THE
PHYSICAL REVIEW
A journal of experimental and theoretical physics established by E. L. Nichols in 1893

VOL. 61, NOS. 11 AND 12 JUNE 1 AND 15, 1942 SECOND SERIES

Further Measurements of the Mesotron Lifetime

BRUNO ROSSI AND KENNETH GREISEN, *Cornell University, Ithaca, New York*
JOYCE C. STEARNS AND DAROL K. FROMAN, *University of Denver, Denver, Colorado*
AND
PHILLIPP G. KOONTZ, *Colorado State College, Fort Collins, Colorado*
(Received March 23, 1942)

The average ranges before decay of two monoenergetic mesotron groups have been measured. Within the statistical errors, the ranges are found to be in the same ratio as the average effective momenta, as theoretically predicted. From the two above measurements, and with a mesotron mass $\mu = 10^8$ ev/c², one obtains the values $\tau_0 = (2.8 \pm 0.3) \times 10^{-6}$ and $\tau_0 = (2.9 \pm 0.7) \times 10^{-6}$ second for the proper lifetime of mesotrons, in excellent agreement with previous measurements by Rossi and Hall.

INTRODUCTION

THE spontaneous disintegration of cosmic-ray mesotrons in the atmosphere has been the subject of many recent investigations.[1–10] The quantity which is experimentally determined is the so-called *average range before decay*. If this quantity is designated by L, dz/L represents the fractional number of mesotrons which disintegrate while traveling the distance dz. L is related to the lifetime of mesotrons at rest, τ_0, by the equation

$$L = p\tau_0/\mu, \tag{1}$$

where μ is the rest mass and p the momentum of the mesotrons. Equation (1) follows immediately from the relativistic transformation formula for time intervals.

The dependence of L on p expressed by Eq. (1) implies that the interpretation of the experimental results is most direct and unambiguous when mesotrons belonging to a narrow momentum interval are recorded. Experiments on monoenergetic groups of mesotrons have been performed by Rossi and Hall,[8] by Nielsen, Ryerson, Nordheim, and Morgan,[10] and by Bernardini, Cacciapuoti, Pancini, Piccioni, and Wick.[9] Under the assumption that the mesotron mass is $\mu = 10^8$ ev/c², the experiments of Rossi and Hall give $\tau_0 = 3.0 \pm 0.4$ microseconds. Rossi and Hall have also compared the average range before decay of a fairly monoenergetic mesotron group with that of all mesotrons with momenta extending from the upper limit of this group to

[1] B. Rossi, N. Hilberry, and J. B. Hoag, Phys. Rev. **56**, 837 (1939); and **57**, 461 (1940).
[2] W. M. Nielsen, C. M. Ryerson, L. W. Nordheim, and K. Z. Morgan, Phys. Rev. **57**, 158 (1940).
[3] M. A. Pomerantz, Phys. Rev. **57**, 3 (1940).
[4] M. Ageno, G. Bernardini, N. B. Cacciapuoti, B. Ferretti, and G. C. Wick, Phys. Rev. **57**, 945 (1940).
[5] H. V. Neher and H. G. Stever, Phys. Rev. **58**, 766 (1940).
[6] N. N. Das Gupta and P. C. Bhattacharya, Proc. Nat. Inst. Sci. Ind. **6**, 713 (1940).
[7] A. Ehmert, Zeits. f. Physik **115**, 333 (1940).
[8] B. Rossi and D. B. Hall, Phys. Rev. **59**, 223 (1941).
[9] G. Bernardini, B. N. Cacciapuoti, E. Pancini, O. Piccioni, and G. C. Wick, Phys. Rev. **60**, 910 (1941).
[10] W. M. Nielsen, C. M. Ryerson, L. W. Nordheim, and K. Z. Morgan, Phys. Rev. **59**, 547 (1941).

infinity. In this way they were able to prove that L is an increasing function of p, in qualitative agreement with Eq. (1). The measurements by Nielsen, Ryerson, Nordheim, and Morgan were, in principle, similar to those of Rossi and Hall. They gave, however, a much smaller value for τ_0, namely, $\tau_0=1.2\pm0.3$ microseconds. Bernardini, Cacciapuoti, Pancini, Piccioni, and Wick found, in various measurements, values of τ_0 ranging from 1.65 ± 0.3 to 3.4 ± 0.3 microseconds. Recently Rasetti has investigated the disintegration of mesotrons by measuring the delay between the stopping of mesotrons in an absorber and the emission from the absorber of decay electrons.[11] He found $\tau_0=1.5\pm0.3$ microseconds.

In view of the disagreement between the above results, further experiments on the disintegration of mesotrons seemed desirable. In the present experiments, the average ranges before decay of two widely separated and fairly monoenergetic groups of mesotrons were measured. The purpose was to obtain a new determination of τ_0 as well as a more quantitative check of the relation between L and p expressed by Eq. (1).

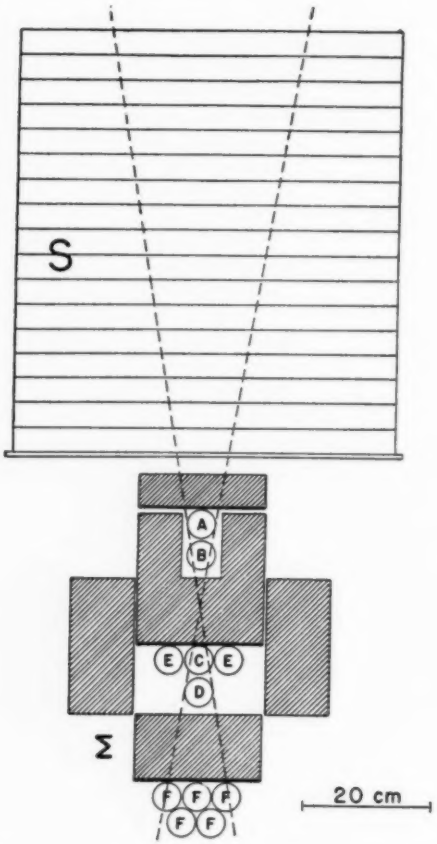

FIG. 1. Geometrical arrangement of counters and absorbers.

[11] F. Rasetti, Phys. Rev. **60**, 198 (1941).

EXPERIMENTAL METHOD

The experimental arrangement (see Fig. 1) was almost identical to the one used by Rossi and Hall.[8] The Geiger-Müller counters had an internal diameter of 4.24 cm. The length of the wire was 20 cm for counters A, B, C, D, and E, and 60 cm for counters F. The five counters F and the two counters E were all connected in parallel. The counter battery F covered completely the solid angle subtended by counters A, B, C, and D. Permanent lead absorbers were placed above counter A and between counter B and counter C. The total thickness of these permanent absorbers, including the material of the frame and the counter walls, was equivalent to 196 g/cm² of lead and was sufficient to stop the soft component of cosmic rays completely. Additional absorbers, S and Σ, could be placed above the apparatus and between counters D and F. The absorber S consisted of thick iron plates and was arranged so as to cover the whole solid angle subtended by counters A, B, C, and D. Its maximum thickness was 485 g/cm² and its total weight was about 5 tons. The absorber Σ consisted of 112 g/cm² of lead plus 2.4 g/cm² of steel and was thus equivalent to 115 g/cm² of lead.

By means of a coincidence-anticoincidence circuit, the two following phenomena were recorded: (1) simultaneous discharges of counters A, B, C, and D irrespective of discharges in counters E or F (coincidences $[ABCD]$), and (2) simultaneous discharges of counters A, B, C, and D not accompanied by a discharge either of counters E or of counters F (anticoincidences $[ABCD\text{–}EF]$). The anticoincidences $[ABCD\text{–}EF]$ were caused by mesotrons stopped in the absorber Σ, apart from a small zero effect, which was determined by removing the absorber Σ. Thus the difference Δ between the number of anticoincidences per minute recorded with and without the absorber Σ was taken as a measure of the number of mesotrons capable of traversing 196 g/cm² of lead plus whatever iron absorber was present in S, and stopped by 115 additional g/cm² of lead.

TABLE I. Summary of the experimental results. $[ABCD]$ and $[ABCD-EF]$ are the number of fourfold coincidences and the number of anticoincidences per minute, respectively. Δ is the difference between the numbers of anticoincidences recorded with and without 115 g/cm² of lead in Σ.

Location	Exp.	Absorber g/cm² S	Absorber g/cm² Σ	Time (minutes)	$[ABCD]$	$[ABCD-EF]$	Δ
Denver $z=1616$ m $h=857$ g/cm²	a	0	0	1332	5.31±0.064	0.031±0.0049	0.290±0.0089
		0	115	5921	5.40±0.030	0.322±0.0074	
	b	285	0	1452	4.32±0.054	0.032±0.0047	0.218±0.0071
		285	115	8600	4.39±0.023	0.250±0.0054	
Echo Lake $z=3240$ m $h=708$ g/cm²	c	0	0	1382	7.71±0.080	0.071±0.0072	0.567±0.014
		0	115	4340	7.64±0.042	0.638±0.012	
	d	200	0	1804	6.23±0.059	0.058±0.0057	0.413±0.011
		200	115	4884	6.27±0.036	0.471±0.0098	
	e	342	0	2273	5.35±0.050	0.047±0.0045	0.310±0.011
		342	115	4540	5.42±0.034	0.357±0.0090	
	f	485	0	3051	4.85±0.040	0.042±0.0037	0.258±0.0073
		485	115	7571	4.73±0.025	0.300±0.0063	

TABLE II. Comparison between the present results and those of Rossi and Hall (reference 8). The lead absorbers have the same thickness in both experiments (196 g/cm² above counter D and 115 g/cm² between the counters D and F).

	Rossi and Hall	Present exp.
$\Delta/[ABCD]$ at Denver with $S=0$	0.0535±0.0015	0.0538±0.0015
$\Delta/[ABCD]$ at Echo Lake with $S=0$	0.074 ±0.005	0.0742±0.0019
$\Delta/[ABCD]$ at Echo Lake with $S=200$ g/cm² Fe	0.0663±0.0020	0.0659±0.0016
$\dfrac{\Delta \text{ at Echo Lake with } S=200 \text{ g/cm}^2 \text{ Fe}}{\Delta \text{ at Denver with } S=0}$	1.43 ±0.06	1.42 ±0.06

We refer the reader to the paper by Rossi and Hall for a critical discussion of the experimental method, in particular of the various phenomena which may be responsible for the zero effect. We wish to point out that in the present experiments we succeeded in reducing the zero effect to a smaller fraction of the counting rate than in the previous experiments of Rossi and Hall, thus decreasing the influence of a possible source of error. As in the experiments by Rossi and Hall, the counters E, together with the lead walls on both sides of the apparatus, were used to eliminate anticoincidences produced by air showers.

EXPERIMENTAL RESULTS

Measurements were taken at Denver (1616 m above sea level) with 0 and with 285 g/cm² of iron in S, and at Echo Lake (3240 m above sea level) with 0, 200, 342, and 485 g/cm² of iron in S. In both locations the apparatus was housed under a tent and the axes of the counters were set in the east-west direction. The results are summarized in Table I.

A significant check of the experimental accuracy is supplied by a comparison between some of our present results and those obtained by Rossi and Hall one year earlier under similar experimental conditions. This comparison is presented in Table II. The excellent agreement between all comparable data lends support to the assumption that the accuracy of the measurements is limited only by the statistical fluctuations.

DISCUSSION OF THE EXPERIMENTAL RESULTS

It is safe to assume that mesotrons lose energy by collision processes only, at least as long as their energy is of the order of 10^9 ev or less.

Under this assumption, a well-defined relation exists between momentum and range of mesotrons, and the quantities listed under Δ in Table I may be taken as a measure of the numbers of mesotrons belonging to definite momentum intervals.

In the evaluation of these momentum intervals, we have used the momentum-range relation calculated by Rossi and Greisen.[12] Following Halpern and Hall, we have applied a correction of 3 percent to the ranges in lead and a correction of 2 percent to the ranges in iron, to account for the density effect in the energy loss by collision (see reference 8, footnote 9). The experimental results, translated to a momentum scale, are represented graphically in Fig. 2.

The four rectangles (*c*), (*d*), (*e*), and (*f*) in Fig. 2 correspond to the four mesotron groups recorded at Echo Lake (measurements *c*, *d*, *e*, and *f* in Table I). The area of each rectangle is proportional to the number of mesotrons (Δ) in the corresponding group, while the base of the rectangle represents the momentum interval. The shaded areas above and below the top of each rectangle indicate the statistical errors of the measurements. Curve *s* represents what seems the most plausible differential momentum spectrum of mesotrons at Echo Lake. In other words, *s* is drawn so that the areas of the rectangles (*c*), (*d*), (*e*), and (*f*) are equal to the areas under the corresponding portions of the curve.

The rectangles (*a*) and (*b*) correspond to the mesotron groups observed at Denver. In plotting these data, the momentum losses between Echo Lake and Denver have been added to the momenta of the observed mesotrons. Thus all the abscissae in Fig. 2 refer to the momenta of mesotrons *at the altitude of Echo Lake.*

For each of the mesotron groups (*a*) and (*b*), the area of the rectangle gives the number of mesotrons at Denver, n_2, while the area under the corresponding portion of the curve *s* gives the number of mesotrons at Echo Lake, n_1. The two numbers should be equal if the mesotrons were stable. The fact that $n_2 < n_1$ is accounted for by the disintegration of mesotrons in the air layer between Echo Lake and Denver.‡ The ratio n_2/n_1 represents the *probability of survival* at the lower station for the mesotrons present at the upper one. This quantity is related to the average range before decay by the equation

$$\log (n_1/n_2) = (z_1 - z_2)/L, \qquad (2)$$

where z_1 and z_2 are the elevations of Echo Lake and Denver, respectively. From the experimental data one calculates the following values of L for the two mesotron groups:

$$L_a = (4.26 \pm 0.46) \times 10^5 \text{ cm},$$
$$L_b = (8.5 \pm 1.9) \times 10^5 \text{ cm}.$$

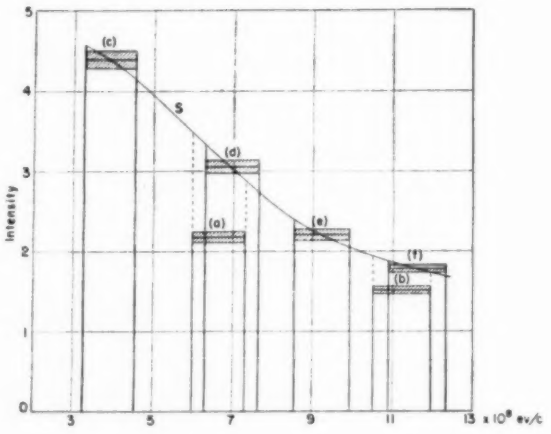

FIG. 2. Graphical representation of the experimental results. Abscissae are the momenta of the mesotrons at the altitude of Echo Lake. Rectangles (a) and (b) refer to measurements at Denver; rectangles (c), (d), (e), and (f) refer to measurements at Echo Lake. The area of each rectangle represents the number of mesotrons recorded in the corresponding momentum interval. Curve *s* represents the differential momentum spectrum of mesotrons at Echo Lake.

[12] B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 240 (1941).

‡ *Note added in the proof:* In this discussion, we have disregarded the possibility of an appreciable influence of mesotron production on our experimental results. It was thought that, even if mesotrons are produced in appreciable number in the air layer between Echo Lake and Denver, the effect on the lifetime measurements would be negligible because an approximately equal number of mesotrons should be produced in the compensating iron absorber. In the light of recent measurements by Regener (Bull. Am. Phys. Soc. **17**, No. 2, abstract No. 17) which show a comparatively large mesotron production at moderate altitudes and a strong dependence of mesotron production on atomic number, the above conclusion may be not completely justified. If more mesotrons are produced in one g/cm² of air than in one g/cm² of iron, as Regener's experiments indicate, the production of mesotrons partly cancels the effect of decay and the value of the lifetime deduced from our measurements is too large. How great the error may be cannot be estimated until more quantitative data about the mesotron production are available.

Since the mesotron momentum changes as the mesotrons travel in the atmosphere, the momentum p in Eq. (1) must be understood as a kind of average between the values of the momentum at the two elevations z_1 and z_2, where the measurements are made. This average is called the *effective momentum* and is defined by Eq. (5) in the paper by Rossi and Hall (see reference 8). According to this equation, the effective momenta in the mesotron groups (a) and (b) range from 4.52×10^8 to 5.86×10^8 ev/c and from 9.03×10^8 to 10.44×10^8 ev/c, respectively. As average effective momenta for the two groups we may take

$$p_a=5.15\times10^8 \text{ ev/c}, \quad \text{and} \quad p_b=9.72\times10^8 \text{ ev/c}.^{13}$$

Comparison of the values of p with the values of L_a and L_b shows that, within the statistical errors, the *average ranges before decay are proportional to the effective momenta*, in agreement with Eq. (1). This equation then yields:

from the measurements on group (a),

$$\tau_0/\mu=(8.3\pm0.9)\times10^{-4} \text{ cm c/ev}$$

from the measurements on group (b),

$$\tau_0/\mu=(8.8\pm2.0)\times10^{-4} \text{ cm c/ev}.$$

If one takes $\mu=10^8$ ev/c^2, the corresponding values of τ_0 are, respectively,

(a) $\tau_0=(8.3\pm0.9)\times10^4$ cm/c, or $\tau_0=(2.8\pm0.3)\times10^{-6}$ sec.

(b) $\tau_0=(8.8\pm2.0)\times10^4$ cm/c, or $\tau_0=(2.9\pm0.7)\times10^{-6}$ sec.

The above results are in excellent agreement with those of Rossi and Hall (reference 8). As a matter of fact, the agreement is even better than it appears, because the difference between the value obtained by Rossi and Hall ($\tau_0=3.0\times10^{-6}$ sec.) and our present value for group (a) ($\tau_0=2.8\times10^{-6}$ sec.) arises entirely from the more accurate method of calculation which we have used.

It is possible to obtain from our measurements a third independent evaluation of the lifetime. The difference between the number of coincidences per minute recorded at Echo Lake with 200 and with 485 g/cm^2 of iron in S gives the number of mesotrons with momenta between 6.30×10^8 and 10.89×10^8 ev/c at z_1. Since 200 g/cm^2 of iron are approximately equivalent to the air layer between Echo Lake and Denver, the difference between the number of coincidences recorded at Denver with 0 and with 285 g/cm^2 of iron gives the number of mesotrons in the same group at z_2. From the ratio between the two differences, one obtains $L=(4.2\pm0.46)\times10^5$ cm. The average effective momentum of the group under consideration may be taken as equal to 6.3×10^8 ev/c. Accordingly, one obtains for the lifetime the value

$$\tau_0=(2.2\pm0.24)\times10^{-6} \text{ sec.}$$

The difference between this value of τ_0 and the values obtained by the anticoincidence method may be accounted for by statistical fluctuations. It is possible, however, that the third determination is subject to errors other than purely statistical. In fact, the data used in the third determination are small differences between large counting rates measured independently. Any fluctuation in the cosmic-ray intensity is bound to affect these data to a much larger extent than the data obtained by the anticoincidence method, in which the significant differences are recorded directly.

For this reason we believe that only the results obtained with the anticoincidence method should be considered in evaluating the most probable value of the lifetime τ_0. By combining our data with those of Rossi and Hall, re-evaluated by our present method, one then obtains

$$\tau_0=(2.8\pm0.2)\times10^{-6} \text{ sec.} \qquad (\text{with } \mu=10^8 \text{ ev/c}^2).$$

[13] Since the observed effects are proportional to $1/p$, as average momentum we have taken the reciprocal of $(1/p)_{Av}$.

Electric and Magnetic Effects of Cosmic Rays

FOSTER EVANS
The University of Colorado, Boulder, Colorado
(Received March 16, 1942)

It is found that slow interstellar electrons moving in the vicinity of the earth under the influence of a radial electric field caused by the earth's interception of cosmic rays as charged particles predominantly of one sign and the magnetic field of the earth's dipole will produce a continuous series of shell currents concentric with the earth. The current density in the shells varies with the inverse fifth power of the distance from the earth's center and the cosine of the latitude. These currents contribute to the earth's field a uniform component parallel to the magnetic axis in a direction from south to north. It is found that if either cosmic-ray intensity or the density of positive ions in the vicinity of the earth varies, there will result a variation in magnetic field intensity at the earth's surface. It is shown that the ratio $(\Delta I/I)/(\Delta H/H)$, where I represents cosmic-ray intensity and H the horizontal component of the earth's magnetic field intensity, for a variation caused by a change in cosmic-ray intensity is of the same order of magnitude as observed experimentally.

INTRODUCTION

IN a previous[1] investigation were considered the electric fields that would result from a net charge carried by primary cosmic rays. It was found that because of the finite electrical conductivity of interstellar space only small, radial fields would be produced in the vicinity of a stellar body which intercepted or emitted cosmic rays as charged particles predominantly of one sign. These fields would have their origin in a small charge on the body and would superimpose a drift velocity on the random motion of slow interstellar electrons producing sufficient current to neutralize a current caused by cosmic rays, so that the net flow of charge to a star would be zero. Since the publication of this material new evidence[2] has come to light which indicates that it is probable that the incoming cosmic radiation consists entirely of protons. Hence the study of the possible effects of charged cosmic-ray particles becomes even more significant.

In the previous work the effect of stellar magnetic moments was neglected. It has been the purpose of the present investigation to introduce into the calculations as applied to the earth the effect of the earth's dipole moment and consider some of the possible consequences.

THE ELECTRIC FIELD

Consider an electron moving in the vicinity of the earth under the influence of a radial electric field $\mathbf{E}_r$ and the magnetic field of the earth's dipole the component of which at right angles to the radial direction is $\mathbf{H}_\lambda$ (e.m.u.). Assume that the axis of the dipole coincides with the earth's axis. If the magnitude of the electron's charge is e (e.s.u.) and it possesses a drift velocity $\mathbf{v}$ toward the center of the earth in a radial direction, there will be a force exerted on it in a westerly direction resulting in a current in an easterly direction along a parallel of latitude. The force will be given by the expression

$$\mathbf{F}=(e/c)\mathbf{v}\times\mathbf{H}_\lambda. \tag{1}$$

This force may be considered equivalent to the force caused by an electric field $\mathbf{E}_e$ (e.s.u.), where

$$\mathbf{E}_e e=(e/c)\mathbf{v}\times\mathbf{H}_\lambda,$$

or

$$\mathbf{E}_e=(1/c)\mathbf{v}\times\mathbf{H}_\lambda. \tag{2}$$

If the density of electrons[3] is n, and v is a constant, the radial current density is

$$\mathbf{J}_r=-ne\mathbf{v}\ \text{(e.s.u.)}.$$

[1] F. Evans, Phys. Rev. **59**, 1 (1941); see also F. L. Mohler, Phys. Rev. **59**, 1043 (1941), and F. Evans, Phys. Rev. **60**, 911 (1941).

[2] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941); W. F. G. Swann, Phys. Rev. **59**, 770 and 836 (1941); G. Cocconi, Phys. Rev. **60**, 532 (1941); see also B. Rossi and K. Greisen, Phys. Rev. **61**, 121 (1942), in which evidence is given for the existence of primary electrons.

[3] Because of their relatively low mobilities the motion of the positive ions is being neglected. The force acting on positive ions moving away from the earth would be in the same direction as that acting on the electrons, so the equivalent electric field for such positive ions would be opposite in sign to $\mathbf{E}_e$.

The situation corresponds to that described in the Hall effect where the Hall coefficient is defined as

$$R' = E_e/J_r H_\lambda = vH_\lambda/necvH_\lambda = 1/nec.$$

If the velocities of the electrons follow a Maxwellian distribution, the Hall coefficient becomes[4]

$$R = 3\pi/8nec. \tag{3}$$

Hence the field $\mathbf{E}_e$ is given by

$$\mathbf{E}_e = -R\mathbf{J}_r \times \mathbf{H}_\lambda.$$

Suppose the current $\mathbf{J}_r$ to be caused by a radial electric field $\mathbf{E}_r$ set up by the earth's interception of charged cosmic-ray particles. The current caused by the cosmic rays themselves is not considered since the region in space in which these considerations are valid is one in which the effect of the earth's magnetic moment on cosmic rays may be neglected. It has been shown[1] that the radial field $\mathbf{E}_r$ at a distance r from the center of the earth is

$$\mathbf{E}_r = -A\mathbf{r}/\sigma r^2, \tag{4}$$

where $4\pi A$ (e.s.u.) is the total current flowing to the earth in the form of cosmic rays, being considered positive if the current flow is in the direction of the unit vector $\mathbf{r}$, and σ (e.s.u.) is the conductivity of interstellar space. Then

$$\mathbf{J}_r = \sigma\mathbf{E}_r = -A\mathbf{r}/r^2$$

and

$$\mathbf{E}_e = +(RA/r^2)\mathbf{r} \times \mathbf{H}_\lambda. \tag{5}$$

The resultant field $\mathbf{E}$ at a distance r from the center of the earth is then

$$\mathbf{E} = \mathbf{E}_r + \mathbf{E}_e = -(A/r^2)(\mathbf{r}/\sigma - R\mathbf{r} \times \mathbf{H}_\lambda). \tag{6}$$

In discussing the effects produced by charged cosmic-ray particles it is convenient to divide the region around the earth as follows: (1) a concentric layer adjacent to the earth of outer radius p_1 in which the paths of cosmic rays are strongly affected by the earth's field and are described in the works of Störmer, Lemaitre, and Vallarta; (2) a layer of outer radius p_2 in which, as far as regards the paths of cosmic-ray particles, the earth's field may be neglected,[5] but in which the motion of the slow interstellar electrons will be affected by the earth's field and hence the electric field will be given by Eq. (6); (3) a region in which the second term of Eq. (6) may be neglected in comparison with the first and the electric field expressed by Eq. (4).

The distance p_1 from the center of the earth at which the effect of the earth's magnetic field on cosmic rays may be neglected is perhaps $2a$, where a is the radius of the earth. The outside radius p_2 of the second layer may be approximated by comparing the magnitudes of $\mathbf{E}_r$ and $\mathbf{E}_e$. Thus if E_e may be neglected where, say, $E_r/E_e = 100$, there results $100 = 1/\sigma RH_\lambda$, where $H_\lambda = M\cos\lambda/p_2^3$, $M = 8\times10^{25}$ (e.m.u.) is the moment of the earth's dipole, λ is the latitude, $\sigma = 4.5\times10^{12}$ (e.s.u.),[6] and R is given by Eq. (3). Upon substitution it is found that in the plane of the magnetic equator $p_2 = 10^8$ km $\backsimeq 15{,}000a$.

THE SHELL CURRENTS

The equivalent electric field $\mathbf{E}_e$ will result in producing an electric current the density of which will be

$$\mathbf{J}_e = \sigma\mathbf{E}_e \text{ (e.s.u.)}.$$

According to Eq. (5) the magnitude of this current density is then, at latitude λ and distance r from the center of the earth, given by

$$J_e = \sigma RAH_\lambda/r^2 = \sigma RAM\cos\lambda/r^5. \tag{7}$$

Hence, beyond the first layer described above, there will be a continuous series of spherical shells of current concentric with the earth. The current density in any shell is proportional to the cosine of the latitude. The magnetic intensity within such a shell can be shown[7] to be uniform and in a direction parallel to the magnetic axis. The intensity of the field at the earth's surface as a result of all the current shells may therefore be determined by calculating the intensity caused by any one shell at the common center of the shells and then summing for all the shells. The integration is carried out over all space outside of region (1) described above, so the lower limit of the integration is p_1. The resultant field intensity

[4] A. H. Wilson, *The Theory of Metals* (Cambridge, 1936), p. 171.

[5] Magnetic effects of other bodies such as the sun are not being considered.

[6] F. L. Mohler, Phys. Rev. **59**, 1043 (1941).

[7] E. H. Vestine and S. Chapman, Terr. Mag. **43**, 351 (1938).

is found to be

$$H''=2\pi\sigma RAM/3cp_1^4 \text{ (e.m.u.)}. \quad (8)$$

After substituting the expression for R from Eq. (3), one finds the horizontal component H' of the magnetic field intensity at the earth's surface caused by these current shells is given by

$$H'=H''\cos\lambda=\pi^2\sigma AM\cos\lambda/4nec^2p_1^4. \quad (9)$$

The following numerical values are substituted into Eq. (9):

$\sigma=4.5\times10^{12}$ e.s.u., $e=4.8\times10^{-10}$ e.s.u.,
$M=8\times10^{25}$ e.m.u., $c=3\times10^{10}$ cm/sec.,
$n=1/\text{cm}^3$, $-4\pi A=0.09$ amp.,[8]
$p_1=2a=1.27\times10^9$ cm, $A=-2.18\times10^7$ e.s.u.

with the result

$$H'=1.68\times10^{-2}\cos\lambda \text{ (e.m.u.)}. \quad (10)$$

If cosmic rays consist only of positively charged particles, the field represented by H'' will contribute to the earth's field a uniform component parallel to the magnetic axis in a direction from south to north and H' will be in a direction so as to augment the horizontal component of the earth's field.

TERRESTRIAL MAGNETIC VARIATIONS

Let H_0 be the horizontal component of the earth's field intensity due to all causes other than the one under discussion, then the total intensity of the horizontal component is $H=H_0+H'$. Suppose for the moment that H_0 is constant, then $\Delta H/H=\Delta H'/H$. From Eq. (9)

$$\Delta H'/H'=\Delta A/A=\Delta I/I,$$

where I is the intensity of cosmic radiation. Hence

$$(\Delta I/I)/(\Delta H/H)=(\Delta H'/H')/(\Delta H'/H)=H/H'.$$

So, if at the equator $H=0.38$ (e.m.u.),

$$(\Delta I/I)/(\Delta H/H)\backsimeq22. \quad (11)$$

A positive correlation between variations in cosmic-ray intensity and horizontal magnetic intensity such as expressed in Eq. (11) has been observed[9] by several investigators during magnetic disturbances and recognized as a world-wide phenomenon. The numerical value[10] of this ratio as observed experimentally is of the same order of magnitude as that shown in Eq. (11), which indicates that magnetic disturbances at the surface of the earth might be caused by a change in the total flow of charge to the earth in the form of cosmic rays. A magnetic storm, then, may be initiated by a sudden decrease in cosmic-ray intensity. This in turn would produce a decrease in the current intensity in the shell currents and, according to Eq. (8), a decrease in the intensity H''. An exact calculation of the orbits of cosmic-ray particles in a field made up of a uniform field superimposed upon that due to a dipole is needed to predict with certainty what would happen, but according to Johnson[11] a decrease of the field intensity inside the shell currents, if the radius of the smallest shell is greater than $3a/2$, would allow an increase in the number of cosmic rays reaching the earth. An increase in A would result, which again according to Eq. (8) would cause an increase in H'' and a subsequent decrease in A, etc. It seems possible then that some sort of oscillatory fluctuation in I and H might result for which the magnetic storm coefficient would be given by Eq. (11).

The possibility that magnetic storms may be produced by particles emitted from the sun has been considered[12] for some time. The possible influence of such particles on the shell currents may be seen as follows. According to Eq. (9) the intensities H' and H'' vary with σ/n, where σ is the conductivity of interstellar space and n is the density of electrons. In previous work σ was found to be given by[13]

$$\sigma=2m^{\frac{1}{2}}e^2\gamma/\alpha(kt)^{\frac{3}{2}}.$$

In this expression α is the ratio n/N_+, where N_+ is the density of positive ions in interstellar space. It is seen then that the field intensity of the

[8] T. H. Johnson, Rev. Mod. Phys. **10**, 237 (1938).
[9] See reference 8, p. 229 for bibliography; also V. F. Hess and E. B. Berry, Phys. Rev. **60**, 746 (1941).
[10] The magnitude of the ratio in Eq. (11) depends to some extent upon the choice of p_1 in the denominator of Eq. (9). The value 22 was obtained by choosing $p_1=2a$. If $p_1=5a/2$ the ratio has the value 54, and if $p_1=3a/2$ the ratio has the value 8. As to which choice of p_1 is the most appropriate or whether or not different choices would apply under different circumstances the writer is not certain.
[11] T. H. Johnson, Terr. Mag. **43**, 1 (1938).
[12] See S. Chapman and J. Bartels, *Geomagnetism* (Oxford, 1940), Vol. 2, Chap. 24, and bibliography pertaining thereto.
[13] F. Evans, Phys. Rev. **60**, 911 (1941).

shell currents varies inversely with N_+. Hence if N_+ increased owing to an emission from the sun of equal numbers of electrons and positive ions, H'' would decrease which would cause A to increase, etc.

A net positive charge carried to the earth by cosmic rays may induce a flow of electrons toward the earth or a flow of positive ions away from the earth. As pointed out earlier in a footnote,[3] positive ions moving away from the earth would produce a current opposite in direction to that caused by the electrons, and if N_+ were greatly increased, the motion of positive ions may be of importance.

It is interesting to note that a variation in the intensity of current in the shell currents may produce the same kind of effect as the equatorial current ring hypothesized by Störmer[14] in connection with his theory of the aurorae. Störmer considered the effect of a westward current ring and supposed that at times of great magnetic disturbance the current in the ring would increase and showed that this would enlarge the angular radius of the auroral zone. Since the direction of the current in the shell currents is eastward it is seen that a decrease in these currents would produce the same kind of effect as an increase in the current in the Störmer ring. Whether or not the magnitude of the effect is sufficient to explain the observed increase in the angular radius of the auroral zone has not been determined.

CONCLUSION

The comparison of the magnitudes of the electric fields $\mathbf{E}_r$ and $\mathbf{E}_\theta$ leads to the conclusion that the effect of the earth's magnetic field on slow interstellar electrons may be neglected at distances greater than approximately the distance from the earth to the sun.

All experimental evidence leads to the conclusion that there are many factors influencing the relation between the intensity of cosmic rays and the intensity of the earth's magnetic field. The theoretical considerations made here seem to indicate that if primary cosmic rays consist of charged particles predominantly of one sign they may be responsible for a portion of the magnetic field intensity observed at the earth's surface, and that variations in cosmic-ray intensity or in the conductivity of interstellar space in the vicinity of the earth may cause a variation in this field and, hence, may contribute to the world-wide terrestrial magnetic variations observed to occur at the earth's surface.

It should be pointed out that Eq. (11) expresses a relation between variation in the horizontal component of magnetic field intensity at the earth's surface and a change in the intensity of cosmic rays entering the earth's atmosphere. The corresponding relation for cosmic-ray intensity at the earth's surface may be somewhat different.

It should also be noted that in these calculations of the magnitude of the magnetic effect produced by the shell currents the possibility of induced currents has not been taken into account. Chapman[15] has suggested that one third of the equatorial variation in horizontal intensity caused by such currents may be due to induced internal currents.

The writer wishes to express his appreciation to Professor Carl Eckart of the University of Chicago for having suggested this investigation and for his continued interest in it, and to Dr. Marcel Schein of the University of Chicago for helpful suggestions.

[14] C. Störmer, Arch. Sci. Phys. Geneva **32**, **33**, 37–104 (1911, 1912).

[15] S. Chapman, Nature **140**, 423 (1937).

Nature of the Soft Component of Cosmic Rays at 3500 Meters Altitude

PIERRE V. AUGER
University of Chicago, Chicago, Illinois
(Received March 28, 1942)

An interpretation is given for the absorption curves of cosmic rays obtained with screens of different atomic numbers. Measurements made in 1935 at the Jungfraujoch (3500 m) with lead and aluminum show the existence of an important number of mesons of relatively small energy in the soft component.

DIFFERENTIAL ABSORPTION OF ELECTRONS AND MESONS

IT has been recently shown[1] that the soft component of cosmic rays, constituted of the particles which are completely absorbed in 15 or 20 cm of lead, does not contain exclusively electrons but also slow mesons. A separation of these two parts, electronic and mesonic, can be attempted by the use of absorbents of very different atomic numbers such as lead and aluminum. The energy losses of the mesons, which are only due to collision (ionization) processes, will be approximately proportional to the number of electrons per cubic centimeter of absorbent, $Z\rho/A$, where ρ is the density, Z the atomic number, and A the atomic weight. This will be also true for electrons if their energy is below the critical value for the type of matter considered, but not for electrons with a higher energy. In this last case the losses will be due mainly to radiative processes, and will depend upon the atomic number by a factor of Z^2.

The thickness of aluminum equivalent to 1 cm of lead for collision processes alone is 3.4 cm, so that the 8 cm of lead which absorb the larger part of the soft component are equivalent to 27 cm of aluminum. On the other hand, *electrons* of 10^9 volts, which are practically stopped by 4 cm of lead, would lose only a fraction of their energy in $4\times3.4=13.6$ cm aluminum, and would not be stopped by half a meter of this metal.

MEASUREMENTS FOR LEAD AND ALUMINUM

The curves in Fig. 1 represent results obtained in 1935 at the International Laboratory of Jungfraujoch, Switzerland, with a triple coincidence counter set arranged in vertical telescope.[2] Screens of lead and aluminum could be interposed up to 20 cm thickness. Curves marked Pb and Al_I give the mean number of counts N per hour as a function of the thickness of the screen for these two metals.

The results for aluminum have been then reduced to the equivalent thicknesses of lead for collision processes. The difference between the new curve, marked Al_{II}, and the Pb curve is due only to the particles showing radiative losses, that is to say, electrons with an energy surpassing notably the critical value for lead. Consider for instance the point for 8 cm Pb, marked N': no electron of reasonable energy (less than 10^{10} ev) can give an effect beyond such a screen. The corresponding point on Al_{II} is situated 30 counts higher: this means that 30 particles per hour are electrons of sufficient energy to traverse 27 cm of aluminum, i.e., electrons of 10^8 volts or more. The group of particles so defined represents 8 percent of the total number and 18 percent of the soft group. A vertical shift of the Al_{II} curve (Al_{III}) brings N and N' in coincidence and the compound curve $O'M'N'R$ obtained represents the absorption of the particles which do not show important radiative losses in aluminum, that is: mesons, and electrons under 10^8 volts.

SLOW MESONS AND ELECTRONS

The lead curve after 20 cm can be considered as practically linear on the scale of Fig. 1. The prolongation toward the origin would give the line RS, so that the point S represents the dividing point between the soft and the hard components. The respective percentages of these components are 46 percent and 54 percent of the

[1] M. Schein, E. O. Wollan, and G. Groetzinger, Phys. Rev. **58**, 1027 (1940); G. Herzog and W. H. Bostick, Phys. Rev. **59**, 122 (1941).

[2] Pierre Auger, L. Leprince-Ringuet, and P. Ehrenfest, J. de Physique [7] **7**, 58 (1936).

total.[3] The hard component contains practically only mesons of larger energies (more than 2.5×10^8 ev). The portion of the soft component absorbed between 8 cm and 20 cm on the lead curve ($N'N''$) contains slower mesons, their energies being comprised between 10^8 and 2.5×10^8 ev: they represent 15 counts, or about 4 percent of the total, and 9 percent of the soft component.

From O' to N' our curve is the reduced Al curve, N' corresponding to the absorption by 27 cm Al. Here slow mesons and electrons are absorbed simultaneously, and the interpretation is more uncertain. But let us consider the point M on the lead curve[4] corresponding to 2.5 cm Pb. The electrons below 10^8 are practically all stopped in that screen, so that MM'' will be equal to the number of slow mesons unabsorbed by 2.5 cm Pb plus the number of electrons above 10^8 ev. But this last number is given by NN' or by MM' which is equivalent so that by subtraction $M'M''$ gives the number of slow mesons. We find only thus a minimum value for this number, because we should add the very slow mesons absorbed by 2.5 cm lead. These particles, which have less than 50 million volts energy, produce more ions per cm than the more energetic electrons or mesons, so that their number can be inferred from the number of thick tracks observed on the cloud-chamber photographs obtained at high altitude. This number, from our own observations on Jungfraujoch and from Anderson's on Pike's Peak, is of the order of 1 percent or 2 percent of the total number of particles. This, added to the value of $M'M''$, gives 60 counts, or 16 percent of the total. We may split this slow meson component into one group with energies below 10^8 and the group with energies between 10^8 and 2.5×10^8 already recognized. By subtraction the first group is found corresponding to 45 counts, or 13 percent of the total and 28 percent of the soft component.

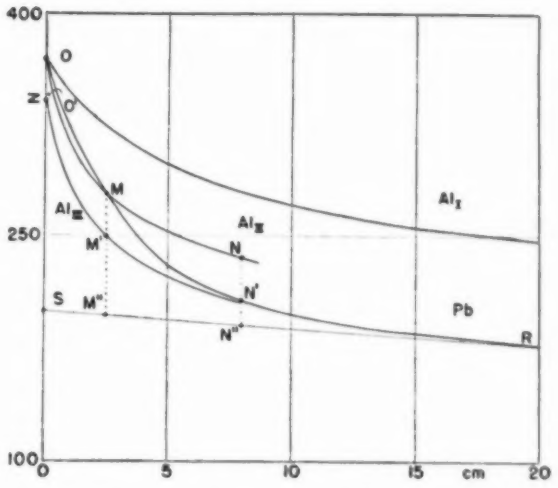

FIG. 1. Absorption curves of the soft component of cosmic rays obtained at 3500 m altitude for lead and aluminum. N is the mean number of counts per hour, plotted against the thickness of the absorber, in centimeters.

Now only the electrons with less than 10^8 ev have not been counted in our balance; because of the thickness of the counter walls (5 mm Cu) no electron of less than 10^7 ev can give a coincidence. So the group of electrons between 10^7 and 10^8 represents the remaining 78 counts of the soft component, i.e., 21 percent of the total. Table I summarizes these results. The accuracy of the numbers given here is unfortunately rather low, especially in the case of values obtained by subtraction. So the number of mesons below 10^8 ev and the number of electrons between 10^7 and 10^8 ev are probably correct only to ±25 percent. The numbers of electrons and mesons above 10^8 ev may be correct to ±15 percent.

TABLE I. Approximate constitution of the soft component at 3500 m altitude.

Particles	Energy (ev)	Number per hour	Percentage in total	Percentage in soft component
Mesons	$>2.5\times10^8$	200	54	—
Mesons	10^8 to 2.5×10^8	15	4	9
Mesons	$<10^8$	45	13	28
Electrons	$>10^8$	30	8	18
Electrons	10^7 to 10^8	78	21	45

[3] A small correction should be introduced by the consideration of the air showers which are frequent at high altitudes; they are not absorbed by the interposed screens, and the counts which they produce are added to the hard component.

[4] From that point on the Pb and Al II curves diverge strongly; in fact, they cross each other, but this is not significant.

Disintegration Schemes of Radioactive Substances. III. I^{131}

J. R. Downing, M. Deutsch, and A. Roberts*
Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received April 7, 1942)

The disintegration of the 8-day isotope of iodine, I^{131}, has been studied by spectrometer and coincidence techniques. The beta-ray spectrum is simple and has an end point of 0.595 ± 0.01 Mev. Each beta-ray is accompanied by two cascade gamma-rays of energies 367 ± 7 and 80 ± 1 kev, respectively. Both gamma-rays are partially internally converted, the 367-kev gamma-ray in the K shell in 0.8 percent of the disintegrations.

INTRODUCTION

THE 7.8-day activity of iodine, widely used for biological tracer work, has been assigned to I^{131}, although a slight possibility exists that it should instead be assigned to I^{129}.[1] This isotope emits beta-rays of moderate energy and also gamma-rays,[1,2] but not x-rays.[3] We have investigated the radiations from this isotope with a view to analyzing the possible modes of disintegration and to discovering the energy levels of the product nucleus Xe^{131}. The accurate understanding of the modes of disintegration is necessary for the calculation of radiation dosages in biological work in which this isotope is of therapeutic value.[4]

PROCEDURES

The coincidence amplifiers and magnetic lens beta- and gamma-ray spectrometer used in this work have been previously described.[5,6] Platinum screen cathode gamma-ray counters were used rather than copper cathode counters because of their considerably higher efficiency in detecting low energy gamma-rays. High efficiency of gamma-ray counters for low energy gamma-radiation is of course an advantage, but it is partially offset by the increased probability that a single quantum from the source causes a coincidence by means of secondary quanta produced by the photoelectric and Compton effects. The number of such spurious coincidences depends of course upon the relative geometry of source and counters. In the usual arrangement with source between counters, the number of spurious coincidences is a minimum with respect to geometry, but still appreciable, and no consistent results on the efficiencies of the counters could be obtained while the source was in this position. This experience is in direct contrast to that of Dunworth,[7] who found that Compton coincidences were negligible with the source between brass cathode counters, which are considerably less efficient for low energy quanta.

In order to eliminate these spurious coincidences, $\frac{5}{8}$ inch of lead was inserted between the two platinum counters used in gamma-gamma-

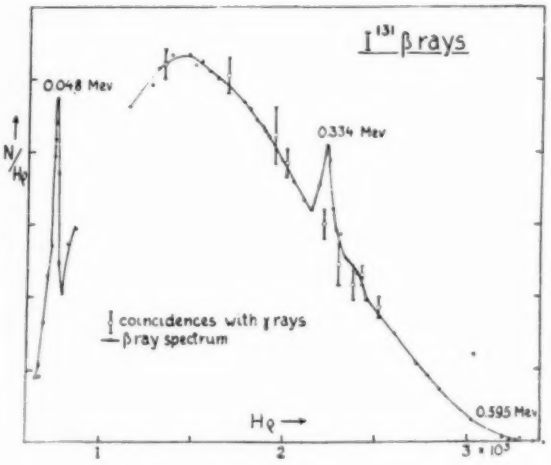

FIG. 1. Beta-ray spectrum and beta-gamma-coincidence spectrum of I^{131}.

* These results were reported at the meeting of the American Physical Society, Princeton, New Jersey, December, 1941.

[1] J. J. Livingood and G. T. Seaborg, Phys. Rev. **54**, 775 (1938); G. T. Seaborg, J. J. Livingood, and J. W. Kennedy, Phys. Rev. **55**, 794 (1939).

[2] G. F. Tape, Phys. Rev. **56**, 965 (1939).

[3] J. G. Hamilton and M. H. Soley, Am. J. Physiol. **127**, 557 (1939).

[4] S. Hertz, A. Roberts, J. H. Means, and R. D. Evans, Trans. Am. Assn. Study of Goiter, p. 260 (1939).

[5] M. Deutsch, Phys. Rev. **59**, 684A (1941).

[6] A. Roberts, J. R. Downing, and M. Deutsch, Phys. Rev. **60**, 544 (1941).

[7] J. V. Dunworth, Rev. Sci. Inst. **11**, 167 (1940).

coincidence measurements, and the source placed symmetrically above the lead so that it could see each counter, and so that scattered quanta would have to penetrate the lead to cause a coincidence. In addition, we have also used a $\frac{1}{4}$-inch lead screen with a small hole over which the source is mounted in beta-gamma-coincidence experiments. These precautions were most essential when quantitative readings on counter efficiency were to be taken.

PREPARATION OF SOURCES

When tellurium is bombarded by deuterons, at least three other radioactive isotopes of iodine besides I^{131} are formed, with half-periods from 25 minutes to 13 days. Rather than work with such a mixture of isotopes, we utilized the fact demonstrated by Livingood and Seaborg,[1] that I^{131} is the decay product of the 25-minute and 1.2-day isomers of Te^{131}. Accordingly, tellurium was bombarded with deuterons in the M.I.T.

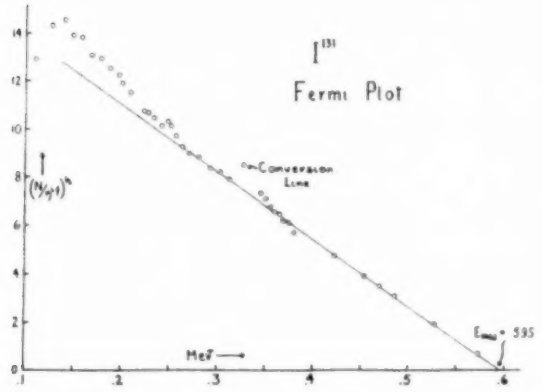

FIG. 2. Fermi plot of the beta-ray spectrum of I^{131}. The departure from linearity may be instrumental in origin.

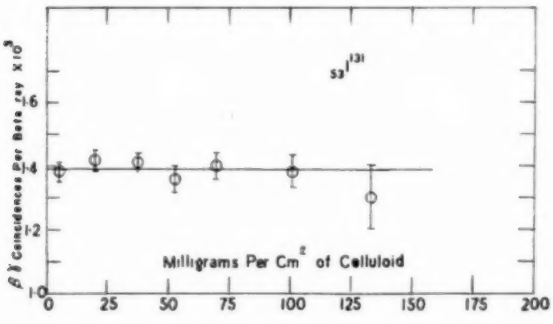

FIG. 3. The number of beta-gamma-coincidences for beta-ray in I^{131} as a function of the amount of absorber in front of the beta-counter. The independence of the rate of the absorber thickness shows the spectrum to be simple.

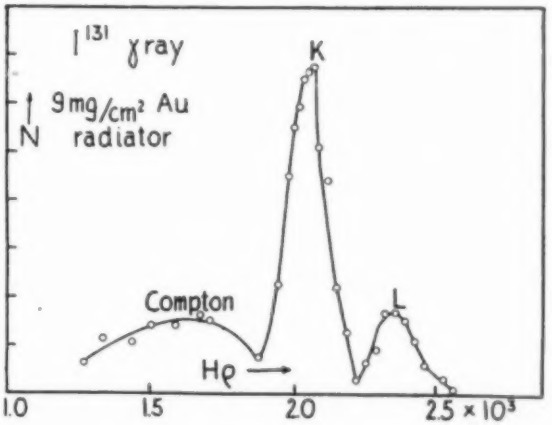

FIG. 4. Secondary electron spectrum excited by the gamma-rays of I^{131}. The photoelectron lines and Compton group are due to a 367-kev gamma-ray.

cyclotron, and the radioactive iodine formed during the bombardment was separated out. The target solution was then permitted to stand for three to five days, the optimum time for growth of maximum I^{131} activity, and the iodine again separated. This gave for all practical purposes a source of radioactively pure I^{131}. It has been shown that another iodine activity grows from tellurium,[8] but this activity is far too weak to interfere with the experiment. The iodine was usually converted to AgI, since it was found that thin sources of NaI, in the presence of air, lost iodine to neighboring surfaces.

RESULTS

The beta-ray spectrum taken with the magnetic lens spectrometer is shown in Fig. 1. The maximum energy, both by inspection, and by extrapolation of the Fermi plot (Fig. 2), is 0.595 ± 0.01 Mev. Within the experimental error, the Fermi plot is a straight line over the range investigated. The shape of the beta-ray spectrum and of the beta-gamma-coincidence spectrum taken on the spectrometer are seen from Fig. 1 to be identical. The absorption of beta-gamma-coincidences (Fig. 3) shows the number of beta-gamma-coincidences per beta-ray to be independent of absorber thickness. All of these observations point to the conclusion that the beta-ray spectrum consists of a single transition. This is verified by integration of the beta-ray

[8] A. Roberts and J. W. Irvine, Jr., Phys. Rev. **59**, 936A (1941).

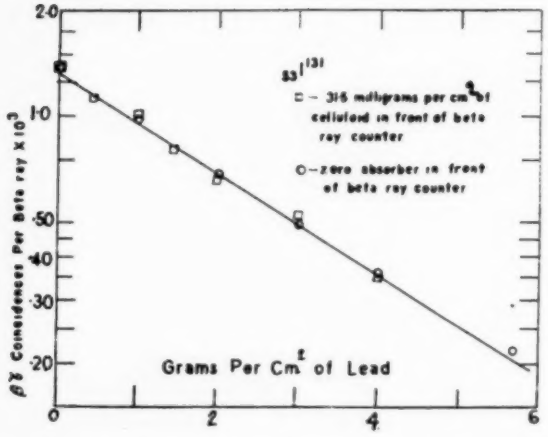

FIG. 5. The absorption of beta-gamma-coincidences by lead absorbers in front of the gamma-ray counter, for two different values of absorber in front of the beta-ray counter. The identity of the two curves shows the identity of the gamma-radiation coinciding with the two sets of beta-rays detected. The absorption of the coinciding gamma-rays is consistent with that of a 367-kev gamma-ray.

spectrum, according to the method[6] previously described.

The secondary electron spectrum of the gamma-rays (Fig. 4) shows a single gamma-ray of energy 367 ± 7 kev. The energy of this line is accurately determined, since it appears not only as Compton and photoelectron secondaries, but also in internal conversion (Fig. 1). No other gamma-ray of energy greater than 180 kev is observed.

The beta-ray spectrum of Fig. 1 shows two peaks due to internal conversion, one due to the 367-kev gamma-ray, and one due to a gamma-ray of 80 kev. The softer conversion line was found with a special thin window counter after the presence of the gamma-ray and its energy had been determined by means of measurements on gamma-gamma-coincidences, as described below.

ABSORPTION OF BETA-GAMMA-COINCIDENCES

To investigate these radiations further, the number of beta-gamma-coincidences was measured with various thicknesses of lead absorber before the gamma-ray counter. The absorption of the beta-gamma-coincidences is identical with the absorption of the gamma-rays alone (Fig. 5) and is not altered by the interposition of a celluloid absorber in front of the beta-counter. We can therefore conclude that all the gamma-rays are associated with the entire beta-ray spectrum since they each coincide equally. Also, over 90 percent of the observed gamma-ray counts are absorbed with the absorption coefficient consistent with a 367-kev gamma-ray, and so we conclude that the efficiency of the gamma-ray counter for detecting the 80-kev gamma-ray is quite low.

ABSORPTION OF GAMMA-GAMMA-COINCIDENCES

On considering the 80-kev gamma-ray which was first revealed by the presence of gamma-gamma-coincidences, we see that the main possibilities are that it is either in cascade with the 367-kev gamma-ray, or that it occurs in an alternate transition in cascade with other gamma-rays which are either too soft or too low in intensity to be observed in the secondary electron spectrum. Orbital electron capture is ruled out by the fact that $_{53}I^{131}$ grows from $_{52}Te^{131}$.

In investigating complex gamma-radiation by coincidence methods the following considerations are of interest. An absorption curve of the gamma-radiation in a single counter will in principle show the several components of the gamma-radiation. If the efficiency of the counter for detecting gamma-rays of equal abundance should vary considerably among the gamma-rays, the apparent intensity of the gamma-rays for which the counter has the lowest efficiency will be small—perhaps small enough so that the radiation will be entirely missed. Quantitatively, if there are two cascade gamma-rays for which the efficiency of the counter is ϵ_1 and ϵ_2, respectively, N disintegrations per minute will produce $N(\epsilon_1+\epsilon_2)$ counts per minute in the gamma-ray counter. If a thickness of absorber in which the absorption coefficients of the gamma-rays are μ_1 and μ_2, respectively, is interposed, the number of counts per minute will be $N(\epsilon_1 e^{-\mu_1 t}+\epsilon_2 e^{-\mu_2 t})$. Thus, while a sum of two exponential absorptions is to be expected, the abundance of each is weighted by the efficiency of the counter for detecting the appropriate radiation.

When coincidences of two cascade gamma-rays are measured, the number of gamma-gamma-coincidences per minute will be $N_{\gamma\gamma}=N(\epsilon_1\epsilon_2'+\epsilon_2\epsilon_1')$, where primed efficiencies are indicated for the second counter. If the counters are of identical construction and differ in efficiency only by a geometrical factor, so that $\epsilon'=k\epsilon$, then

$N_{\gamma\gamma}=2Nk\epsilon_1\epsilon_2$.[9] Now if an absorber is placed in front of one gamma-ray counter only, the number of gamma-gamma-coincidences will be $N_{\gamma\gamma}=N(k\epsilon_1\epsilon_2e^{-\mu_2 t}+k\epsilon_2\epsilon_1e^{-\mu_1 t})=kN\epsilon_1\epsilon_2(e^{-\mu_1 t}+e^{-\mu_2 t})$.[10] This represents a combination of the same exponentials as the absorption in a single counter, but the two gamma-rays are now equally weighted, and the less efficient gamma-ray more easily observed. Curve 3 in Fig. 6 shows the absorption of gamma-gamma-coincidences with lead absorber in front of one counter. The harder component has the absorption characteristic of the 367-kev gamma-ray, and the other gamma-ray is much softer.

In view of this evidence, we may assume that the 80-kev gamma-ray is in cascade with the 367-kev gamma-ray.

In addition, measurements may be taken with absorber in front of both counters, the absorbers always being of equal thickness. In this case the number of coincidences is $N_{\gamma\gamma}=N(k\epsilon_1e^{-\mu_1 t}\epsilon_2e^{-\mu_2 t}+k\epsilon_2e^{-\mu_2 t}\epsilon_1e^{-\mu_1 t})=2kN\epsilon_1\epsilon_2\exp-(\mu_1+\mu_2)t$.[11] Here a single absorption should be observed, with an apparent absorption coefficient $\mu_1+\mu_2$. Figure 6 shows the absorption curve obtained with lead. It is notable that a simple exponential absorption is expected only in the case when there are only two different gamma-rays present.

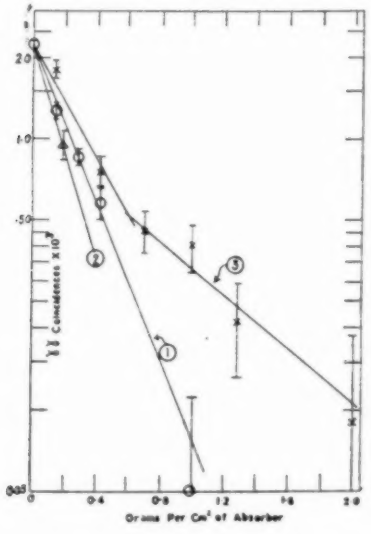

FIG. 6. Curve 3. Absorption of gamma-gamma-coincidences by lead absorber in front of one counter. Curve 1. Absorption of gamma-gamma-coincidences by lead absorber in front of both counters. Curve 2. Absorption of gamma-gamma-coincidences by tin absorbers in front of both counters.

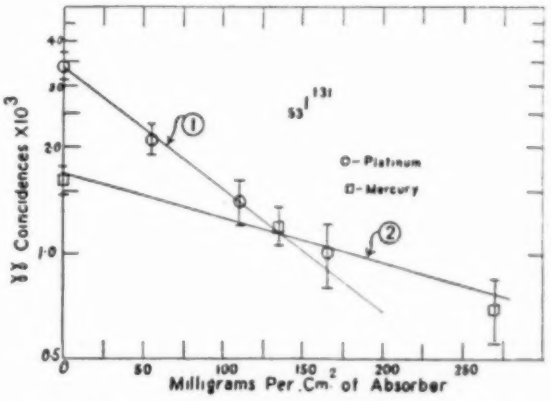

FIG. 7. Critical absorption of gamma-gamma-coincidences. Curve 1. Pt absorbers. Curve 2. Hg absorbers. Curves taken with different source strengths.

From these two experiments the absorption coefficient of the soft radiation in lead is obtained. However, there are two energies of gamma-radiation for which lead has the observed absorption coefficient of 4 $cm^2\,g^{-1}$ one on either side of the K-absorption limit. Absorption in tin (Fig. 6) showed the energy to be below the K edge of lead, and then critical absorption in Pt and Hg (Fig. 7) gave the energy as 80 ± 1 kev. After this determination of the energy, confirmation of the value was found in the discovery of the conversion line to be expected for such low energy radiation, as shown in Fig. 1. It is of interest that Mitchell, Langer, and McDaniel[12] found a 70-kev gamma-ray in cascade with a considerably harder gamma-ray in Sb^{124} by similar methods (although not by critical absorption).

EFFICIENCY MEASUREMENTS

The exact efficiency of a gamma-ray counter for each of the two gamma-rays can be found by measuring both beta-gamma- and gamma-

[9] For n cascade γ-rays the number is

$$N_{\gamma\gamma}=kN\sum_{i,j}^{n}\epsilon_i\epsilon_j \quad (i\neq j).$$

[10] For n cascade γ-rays,

$$N_{\gamma\gamma}=kN\sum_{i,j}^{n}\epsilon_i\epsilon_j(e^{-\mu_i t}+e^{-\mu_j t}) \quad (i<j).$$

[11] For n cascade γ-rays the number is

$$N_{\gamma\gamma}=2kN\sum_{i,j}^{n}\epsilon_i\epsilon_je^{-(\mu_i+\mu_j)t} \quad (i<j).$$

[12] A. C. G. Mitchell, L. M. Langer, and P. W. McDaniel, Phys. Rev. **57**, 1107 (1940).

gamma-coincidences with the same geometry of source and gamma-ray counter, as was pointed out by Dunworth.[7] The number of beta-gamma-coincidences per beta-ray recorded is $N\beta_\gamma/N\epsilon_\beta = \epsilon_1+\epsilon_2$ and the number of gamma-gamma-ray coincidences per gamma-ray recorded in a gamma-ray counter substituted for the beta-ray counter is $N_{\gamma\gamma}/Nk(\epsilon_1+\epsilon_2)=2\epsilon_1\epsilon_2/(\epsilon_1+\epsilon_2)$, provided that the counters differ in efficiency by only a geometrical factor. In the geometry in which this experiment was performed, the number of beta-gamma-coincidences per beta-ray was 0.82×10^{-3}, and the number of gamma-gamma-coincidences per gamma-ray 0.145×10^{-3}. On solving the equations for ϵ_1 and ϵ_2, the values $\epsilon_1=0.74\times10^{-3}$ and $\epsilon_2=0.07\times10^{-3}$ are obtained. Assigning the higher efficiency to the 367-kev gamma-ray, we see that the observation that about 90 percent of the gamma-ray counts are due to it is predicted by the efficiencies.

DIRECT MEASUREMENT OF INTERNAL CONVERSION COEFFICIENT

By mounting a source in the spectrometer on a thin window, it is possible to observe coincidences between beta-rays emitted through this window and conversion electrons focused by the spectrometer (and of course between conversion electrons emitted through the window and beta-rays focused by the spectrometer, as well as between beta- and gamma-rays (Fig. 8)). The number of conversion electron-beta-coincidences per recorded beta-ray permits a direct calculation of the fraction of disintegrations giving conversion electrons, provided the transmission of the spectrometer is known. Thus, in the case of the 332-kev conversion electrons produced in the K shell by the 367-kev gamma-ray, we observe 6.5×10^{-5} electron-beta-coincidence (above the background) per recorded beta-ray. The transmission of the spectrometer is 0.8 percent, and thus the number of K conversion electrons per disintegration is $6.5\times10^{-5}/0.008$ or 8×10^{-3} electron per disintegration. The L conversion line is not resolved, and is estimated not to exceed 25 percent of the K conversion. The assumptions involved in this calculation are that the beta-counter counting the focused conversion electrons is 100 percent efficient, and that the conversion electrons are equally likely to accompany any observed beta-ray. The latter assumption is true because the beta-ray spectrum has been shown to be simple; furthermore, interposing absorber to cut out part of the beta-ray spectrum does not change the electron-beta-coincidence rate per beta-ray recorded.

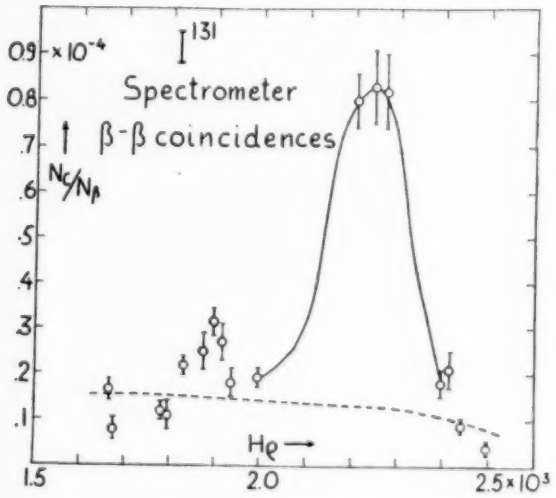

FIG. 8. Conversion electron-beta-ray coincidences as taken on the spectrometer.

The observed conversion coefficient is verified by a calculation of the height of the conversion line relative to the continuous spectrum (Fig. 1) if we take into account the line width and the shape of the spectrum. It is worth noting how much more prominent the conversion line appears in the electron-beta-coincidence spectrum (Fig. 8) than in the continuum (Fig. 1).

The observed peak in the electron-beta-coincidence spectrum at 250 kev may perhaps be due to another gamma-ray giving perhaps a fifth as many conversion electrons as the 367-kev line. No other evidence for such a gamma-ray has been found, and the line may be due to some secondary effect, as for example coincidences between beta-rays and Comptons focused by the spectrometer. The low coincidence rate necessary in electron-beta-coincidence measurements, where the individual counting rates are perhaps 60 and 20,000 counts per minute, respectively, makes the taking of accurate data somewhat difficult.

MATRIX ELEMENT

Using the universal time constant of the Fermi theory $\tau=3000$ sec. as given by Gronblom,[13] and

[13] B. O. Gronblom, Phys. Rev. **56**, 508 (1939).

the values of the $F(Z, \eta)$ transition probability function given by Evans,[14] we find for the matrix element for the $I^{131}-Xe^{131}$ transition the value $G^2=5\times10^{-4}$.

The small value of the matrix element probably means that the beta-ray transition is forbidden. The beta-transitions to the ground state and the lower excited state are not present to as much as 2 percent of the main transition, so that they must be even more highly forbidden.

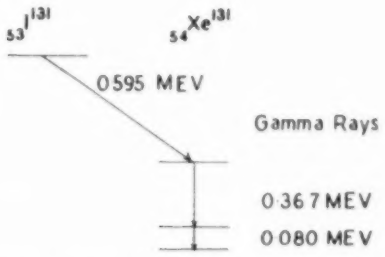

FIG. 9. Probable disintegration scheme of I^{131}. The order of emission of the gamma-rays is not known.

ELECTRIC MULTIPOLE ORDER OF THE GAMMA-RAYS

No theory of internal conversion probabilities for the region of $Z\sim53$ has been given, so far as we are aware. However, by "interpolating" between the theory for low Z[15] and the theory for high Z[16] which predict, respectively, dependence on Z^3 and Z^4, we find that the observed internal conversion coefficient of 0.008 for the 367-kev gamma-ray is probably characteristic of the emission of either electric dipole or quadrupole radiation. Our measurements on the low energy conversion electrons of the 80-kev gamma-ray were not sufficiently accurate to determine the conversion coefficient, mainly because of uncertainty as to the transmission of the counter window. In this case, however, the lifetime of the excited state against emission of an 80-kev gamma-ray would be so long for any but quadrupole[17] or dipole radiation that no coincidences with this gamma-ray would have been observed.

In order to account for the absence of 447 $(=367+80)$ kev radiation, it is necessary to suppose that there is an angular momentum difference between ground and 447-kev levels of at least two units if the states have opposite parity. If the assignment of the activity to mass number 131 is correct, then since the angular momentum of the ground state of Xe^{131} is $\frac{3}{2}$, the angular momentum of the 447-kev level must be at least 7/2. The angular momentum of the ground state of I^{131} is then at least 9/2.

Since I^{131} grows from the 25-minute Te^{131}, a consideration of the angular momentum of the ground state of this nucleus is of interest, especially since this nucleus possesses an isomeric state of half-period 1.2 days, 177 kev above the ground state, estimated by Helmholz to have an angular momentum differing from that of the ground state by at least three units.[18] It is not known whether the 25-minute period is accompanied by gamma-radiation. If it should be found not to emit gamma-radiation, then it will be reasonably certain that of the two isomeric states it is the ground state of Te^{131} which has the higher angular momentum.

The mode of disintegration of I^{131} (Fig. 9) seems sufficiently well-established to make it a useful substance for the calibration of the efficiency of gamma-ray counters.

ACKNOWLEDGMENTS

This research was supported in part by a grant from the John and Mary R. Markle Foundation, for the use of radioactive iodine in thyroid studies. We are grateful for the continued interest and encouragement of Professor Robley D. Evans, and for the cooperation of Professor M. S. Livingston and the crew of the M.I.T. cyclotron. We wish also to express our thanks to Dr. J. W. Irvine, Jr., who performed all the chemical separations.

[14] R. D. Evans, "Introduction to the atomic nucleus," M.I.T. course notes.
[15] S. M. Dancoff and P. Morrison, Phys. Rev. **55**, 122 (1939).
[16] H. R. Hulme, N. F. Mott, F. Oppenheimer, H. M. Taylor, Proc. Roy. Soc. **A155**, 315 (1936).
[17] I. S. Lowen, Phys. Rev. **59**, 835 (1941).
[18] A. C. Helmholz, Phys. Rev. **60**, 415 (1941).

Experimental Evidence for the Existence of a Neutrino

JAMES S. ALLEN
Kansas State College, Manhattan, Kansas

(Received March 16, 1942)

Radioactive Be^7 was deposited on a platinum foil by means of a new evaporation technique. An electron multiplier tube was employed to count the recoil nuclei produced in the reaction, $Be^7+e_K \rightarrow Li^7+\eta+Q$. The maximum energy of the recoils was about 40 to 45 electron volts compared with the value of 58 electron volts to be expected for a neutrino of zero rest mass. An attempt was made to detect coincidences caused by the emission in opposite directions of a gamma-ray and a recoil nucleus. The observed coincidences were less than two percent of those expected for gamma-ray recoils. Apparently the recoils were caused by the emission of a neutrino and not by the emission of a gamma-ray.

INTRODUCTION

THE assumption of the existence of a neutrino is necessary for the conservation of spin and energy in the continuous beta-ray spectrum. Since the neutrino has no charge, an extremely small magnetic moment (if it has one at all), and a very small rest mass, probably the only experimental method for its detection is the observation of the recoil of the nucleus produced in a radioactive decay requiring the emission of a neutrino. Since the beta-ray decay is essentially a three-body process, it is necessary to measure the momenta of both the electron and the nucleus and also the angle between these two momenta in order to find the momentum of the neutrino and finally its mass.

Crane and Halpern[1] attempted to discover the neutrino by measuring the recoil of the electrons and nuclei produced in the disintegration of radiochlorine. Cl^{38} emits negative electrons and has a half-life of approximately 37 minutes. The radioactive substance was introduced into a cloud chamber as a gas, ethylene dichloride. The momentum of an electron emitted during the decay of a radioactive atom could be measured from the curvature of the cloud track in a magnetic field. However, the energy of a recoil nucleus was so small that only a cluster of droplets at the origin of a beta-ray track was produced in the chamber. Since little is known about the energy range relation of very slow atoms in gases, the momenta of the recoil nuclei could not be measured with any accuracy. Although this method was refined somewhat in another experiment, no very definite evidence regarding the neutrino was discovered. The authors concluded that the observed recoil momenta were greater than expected, when no neutrino was assumed.

Leipunski[2] has given a very brief report of an experiment in which radiocarbon was used. C^{11} has a half-life of about 18 minutes and is a positron emitter. The C^{11} was adsorbed as CO_2 gas on a plate cooled by liquid air. The recoil nuclei were accelerated from the plate to a cup-shaped disk by a potential of 5000 volts. Secondary electrons ejected from this disk were recorded by a point counter placed near it. The energy of the recoils was measured by a retarding field between the source plate and a grid. The author concluded that his retarding potential data showed relatively more recoils at the high energy end of the curve than predicted without the assumption of a neutrino.

The decay process involving the capture of an orbital K electron offers another possibility for the detection of the neutrino. The decay of Be^7 is the best example of this process. Kan Chang Wang[3] recently has suggested the use of this substance in a neutrino experiment. The most extensive work on the properties of Be^7 has been done by Rumbaugh, Roberts, and Hafstad.[4] According to these authors, the nuclear reac-

[1] H. R. Crane and J. Halpern, Phys. Rev. **53**, 789 (1938) and Phys. Rev. **56**, 232 (1939).

[2] A. I. Leipunski, Proc. Camb. Phil. Soc. **32**, 301 (1936).
[3] Kan Chang Wang, Phys. Rev. **61**, 97 (1942).
[4] Rumbaugh, Roberts, and Hafstad, Phys. Rev. **54**, 657 (1938).

tions are

$$\left.\begin{aligned} &Li^6+D^2\rightarrow Be^7+n+(3.3\ \text{Mev})\\ &Be^7+e_K\rightarrow Li^7+\eta+(1\ \text{Mev})\\ &Be^7+e_K\rightarrow (Li^7)^*+\eta+(0.55\ \text{Mev})\\ &(Li^7)^*\rightarrow Li^7+h\nu+(0.45\ \text{Mev}) \end{aligned}\right\}\ \text{half-life, 43 days}$$

where e_K, n, and η represent, respectively, a K electron, a neutron, and a neutrino. The decay process is unique in that neither positive electrons nor negative electrons are emitted. The decay is indicated solely by the 0.45-Mev gamma-rays which were shown to be emitted in about one-tenth of the total number of disintegrations. According to the more recent experiments of Haxby[5] and collaborators on the threshold for the reaction $Li^7(p, n)Be^7$, the atomic mass difference Be^7-Li^7 is 0.87 Mev. Therefore, the energy released during the decay of Be^7 is 0.87 Mev instead of 1.0 Mev.

Since the Be^7 decay is not complicated by the emission of electrons, the recoil of the nucleus, if observed, should be entirely due to the ejection of the neutrino. It is necessary only to measure the momenta of the recoil Li^7 nuclei since it is difficult to see how the energy and momentum can be carried away without the neutrino. With the assumption of zero rest mass for the neutrino, the recoil Li^7 nuclei should have a maximum energy of 58 electron volts. The Li^7 recoil nuclei resulting from the emission of the 0.45-Mev gamma should have a maximum energy of 15.6 electron volts.

Since the recoils have so little energy, it is evident that the experiment must be carried out in a vacuum. The electron multiplier tube offered an excellent possibility of detecting the slow recoil atoms or ions.

PREPARATION OF THE RADIOACTIVE SOURCE

Since it was desirable that the recoil Li^7 nuclei be ejected from the source as positive ions, it was evident that the Be^7 should be placed on a platinum surface. According to the well-known theory of surface ionization, the ejected Li^7 atoms should be ionized upon leaving the metal surface since the electron work function of platinum is much greater than the first ionization potential of lithium.

[5] Haxby, Shoupp, Stephens, and Wells, Phys. Rev. **58**, 1035 (1940).

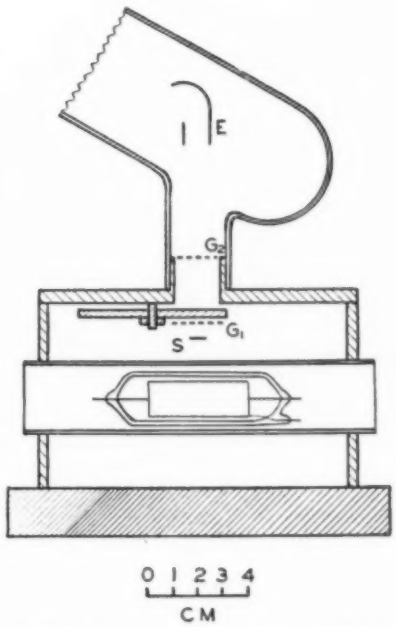

FIG. 1. Experimental arrangement of G-M and electron multiplier tubes.

The first experiments were carried out with a sample of lithium metal that had been bombarded with 8-Mev deuterons in the University of Chicago cyclotron. The lithium was converted to LiCl. After the salt had been dried, a sample was placed in a small steel furnace and evaporated in a vacuum. The evaporated LiCl was collected in a beaker inverted over the furnace. It was found that the total activity remained in the furnace although practically all the sample had been evaporated.

A LiF sample was obtained which had been bombarded with 250-microampere hours of 8-Mev deuterons. A sample of this salt was fused to a strip of one mil thick platinum foil. The activity was measured with a G-M tube and then the material was evaporated at a temperature of about 800°C in a vacuum. The activity of the strip after the complete evaporation of all the LiF was 80 to 90 percent of the original activity. This suggested that the BeF_2 was reduced to Be in the presence of the alkali metal and remained as metallic beryllium. This process was continued until the whole sample had been placed on the platinum strip covering an area of about one square centimeter.

The strip was heated to a temperature of about 1450°C for several hours in a vacuum. Although

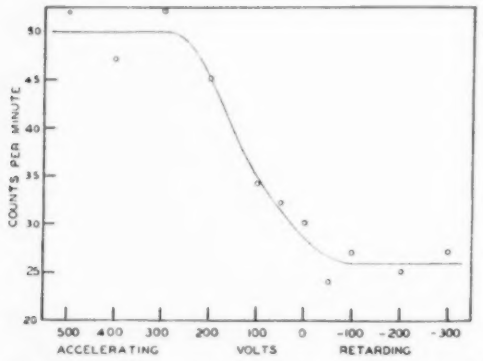

FIG. 2. Retarding potential curve for recoil ions produced by the disintegration of Be^7.

considerable platinum was evaporated, very little activity was lost. This indicated that the radioactive atoms had diffused into the metal. If the platinum could be evaporated rapidly enough, some of the radioactive atoms should be exposed on the surface. However, it remained to be seen whether or not a sufficient surface concentration of radioactive atoms could be obtained in this manner. During the rapid evaporation the temperature of the strip was raised too high and the foil melted through at the center. The pieces of this strip contained about 50 percent of the original activity and were used in the neutrino experiment. The source was spot welded to a tantalum strip so that it could be heated by a current passed through the tantalum.

The radioactivity was identified as that of Be^7 by measuring the absorption coefficient of the radiation in lead. This corresponded to a gamma-ray of about 0.45 Mev. The half-life was found to be in agreement with the value of 43 days reported by Rumbaugh, Roberts, and Hafstad.[4]

EXPERIMENTAL PROCEDURE

A diagram of the apparatus used is shown in Fig. 1. The electron multiplier was of the type described by Allen[6] and had 11 beryllium-covered electrodes. The first electrode E was at a potential of about 3.6 kv negative with respect to ground. The platinum source strip S was supported by two copper rods passing through the base of the apparatus and could be heated by a current sent through these electrodes. A small G-M tube was placed inside a brass tube having a wall thickness of 1/32 inch. Since this tube passed through the outer walls of the vacuum chamber, it was not necessary to bring the G-M tube leads through the vacuum. The multiplier tube could be shut off from the rest of the apparatus during the heating of the source by a gate of $\frac{1}{8}$-inch steel rotated by means of a magnet. The grids G_1 and G_2 were of copper screen; G_2 was at ground potential while G_1 was supported by insulators. A three-stage oil diffusion pump was used to evacuate the apparatus.

Since the pulses from the multiplier tube have an almost random distribution in size, it was necessary to use a pulse equalizing circuit before coincidences between pulses from both the G-M tube and the multiplier tube could be obtained. The multiplier tube pulses were amplified in a two-stage resistance capacity coupled circuit with considerable degeneration between the second and first tube. The pulse equalizer consisted of a multivibrator circuit with time constants sufficiently small so that the width of the pulses was not increased. A high negative grid bias at the second tube kept the circuit from oscillating after a pulse had tripped it. This circuit was found to be extremely convenient since by suitable adjustment of the grid bias voltage, the amplifier noise could be eliminated and all the pulses higher than this noise level brought to a uniform height.

The pulses from the G-M tube were amplified by means of a Neher-Harper circuit. For co-

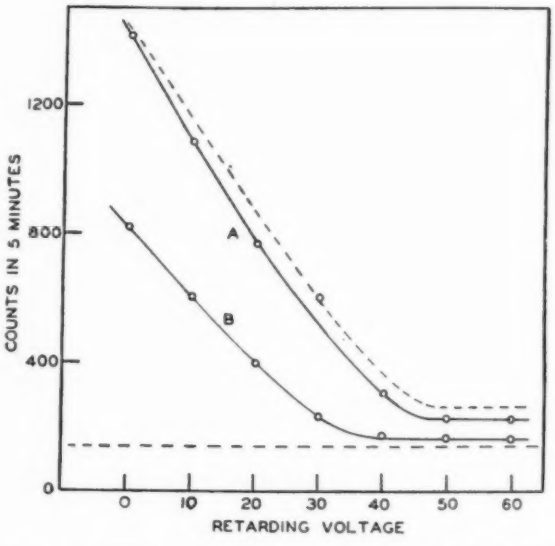

FIG. 3. Retarding potential curves for recoil ions. The horizontal dotted line represents the background counting rate.

[6] James S. Allen, Rev. Sci. Inst. **12**, 484 (1941).

incident counting the pulses from both circuits were mixed in a self-stopping thyratron stage. A scale-of-eight circuit was used to record the pulses.

RESULTS

Before the radioactive source was placed in the apparatus, the multiplier tube had a background counting rate of about four per minute. During the experiment some Li or LiF was evaporated onto the electrodes and the background increased to 40 per minute.

When the Be^7 source was placed in the apparatus, no recoil ions could be detected. However, after the source had been heated to 1000°C for several minutes and then allowed to return to room temperature, the counting rate increased. It was found that a retarding potential of 50 to 100 volts on grid G_1 reduced the counting rate to the background value. The closing of the steel gate produced the same result.

Figure 2 represents one of the first retarding potential curves obtained for the recoil nuclei. Both grids were at ground potential and the voltage was applied between the source and the nearest grid. It is evident from these data that the recoils have a maximum energy of about 50 electron volts. A potential of 300 volts is sufficient to produce a saturation current of recoil ions.

A considerable gain in intensity was obtained by first accelerating the recoils from the source to grid G_1 by a potential of 100 volts or more. The retarding potential was placed between grids G_1 and G_2. Since the recoil ions have so little energy, it was expected that the counting rate would depend upon the heat treatment of the source. Figure 3 shows this variation of the counting rate. The recoil ions were accelerated from the source to grid G_1 by 176 volts and then retarded by 176 volts plus an adjustable retarding voltage. The data for curve A were taken about one hour after a short heating of the source, whereas that for curve B was taken about one hour after these data. Curve A cuts the background line at about 47 volts and curve B cuts it at 41 volts. Apparently sufficient gas has been adsorbed on the source to reduce the energy of the ions by about 6 electron volts.

As a result of a number of measurements of the decrease in the counting rate as a function of time, it was determined that the rate decreased

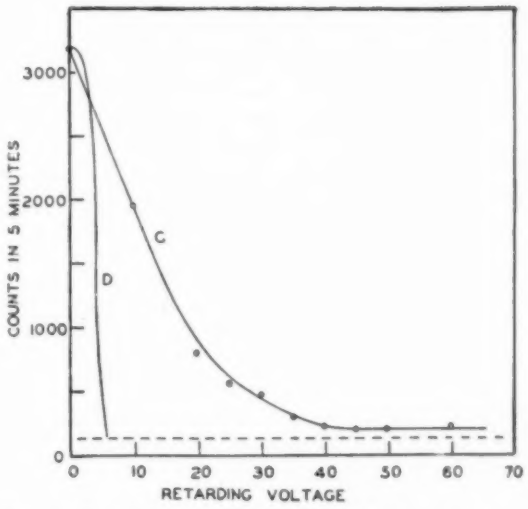

FIG. 4. Curve C is a retarding potential curve for recoil ions whereas curve D is for positive ions emitted from a hot platinum filament. The background counting rate is represented by the dotted line.

to one-half the original value in forty minutes. This decrease appeared to be a linear function of the time if the measurements were made ten minutes or more after the heating of the source. The dotted curve just above curve A represents the correction to A if we assume that the decrease in the counting rate due to the adsorption of gas on the source was a linear function of the time. The correction raises the maximum of the recoil energy to 48 electron volts.

The horizontal dotted line represents the counting rate when the steel gate was closed. The small increase in the counting rate with the gate open and the retarding potential greater than 50 volts is due probably to neutral recoil atoms. The fact that this effect varies with the heat treatment of the source rules out either negative electrons or positrons since these should have no difficulty in penetrating the gas layer. These data indicate that Be^7 emits extremely few, if any, positive or negative electrons since positrons of almost any energy and negative electrons having energies greater than 3.6 kev would have been detected.

Figure 4 represents data taken a short time after the source had been heated for several minutes to a temperature of 800 to 900°C. The counting rate was considerably higher than that for curves A and B. In order to test the accuracy of the retarding potential measurements, the radioactive source was replaced with a strip of

platinum foil which had been treated with a small quantity of LiF in the same manner as the radioactive source. A copious emission of positive ions was obtained when the strip was heated to a few hundred degrees C. No emission was noticed at room temperature. Curve *D* represents the data for these ions. The fact that the ions cut the axis at 6 volts retarding potential can be explained by the penetration through grid G_2 of the strong electric field from the first electrode of the multiplier tube. Thus the observed values of the retarding potentials for the recoils should be decreased by 6 volts.

Although the recoil nuclei appear to have a maximum energy greater than the 15.6 electron volts predicted assuming that they are due to the recoil of the 0.45-Mev gamma-ray, the possibility remained that for some unexplained reason they were, after all, due to this gamma-ray. There remained the additional possibility that the recoils were due to the emission of a 0.87-Mev gamma-ray during the Be^7 disintegration. Although Maier-Leibnitz[7] failed to detect gamma-rays of this energy in a cloud-chamber experiment, it was deemed advisable to test whether or not gamma-rays were accompanying the observed recoils. In order to investigate these possibilities the coincidence experiments to be described in the next section were carried out.

COINCIDENCE COUNTING

The resolving time of the coincidence circuits was determined by removing the G-M tube to one side and adjusting the position of a gamma-ray source so that the counting rate was nearly equal to that observed in the actual experiment. The multiplier tube counting rate was produced by an alpha-particle source. This counting rate also was approximately equal to that observed in the experiment. A resolving time of $3.95 \pm 0.22 \times 10^{-7}$ min. was observed.

In order to predict the number of coincidences to be observed if the recoils were due to a gamma-ray, it was necessary to have at least an approximate value of the efficiencies of both tubes. Since it was impossible to measure directly the efficiency of the multiplier tube for 3- to 4-kev positive ions, measurements were made for alpha-particles. A comparison was made between the counting rate obtained with either the multiplier tube or a parallel plate ionization chamber placed over the same slit system. An ionium source was used. This emits alpha-particles having a range of about 2.8 cm of air. The range was reduced to about 1.4 cm by a mica foil. It was found that the counting rates were the same. This indicates that the multiplier tube records every alpha-particle that hits the first electrode. There is reason to expect that the efficiency for the counting of slow positive ions is likewise about 100 percent.

Since the G-M tube subtended a larger solid angle at the source than did the first electrode of the multiplier tube, every recoil produced by a gamma-ray and recorded by the multiplier tube should be accompanied by the passage of the gamma-ray through the G-M counter. Of course, this assumes that the recoil nucleus and gamma-ray go off in opposite directions. The data of Von Droste[8] and Dunworth[9] give the absolute efficiency of a G-M tube similar to that used in this experiment as about two percent for 1000-kev and one percent for 500-kev gamma-rays. Assuming that the efficiency of the tube used in this experiment was of the same magnitude, one finds that the coincidences to be expected for gamma-ray recoils would be about one or two percent of the multiplier tube counting rate.

In the actual coincidence experiment the G-M tube was placed in the position shown in Fig. 1. The G-M tube rate was 190 counts per minute. The multiplier tube counting rate varied from about 200 to 5000 counts per minute depending upon the heat treatment of the source. Coincidences were recorded during either one-half or one-hour intervals. The multiplier tube rate was taken to be the average of readings taken just before and after the coincidence readings. The number of chance coincidences to be expected was calculated from the relation,

$$A = 2\tau N_1 N_2,$$

where A is the number of accidentals per minute, τ is the resolving time in minutes, and N_1 and N_2 are, respectively, the counting rates of the G-M tube and the electron multiplier tube. A typical set of data is given: $N_1 = 190$ counts per minute,

[7] H. Maier-Leibnitz, Naturwiss. **37**, 614 (1938).

[8] G. Von Droste, Zeits. f. Physik **100**, 529 (1936).

[9] J. V. Dunworth, Rev. Sci. Inst. **11**, 167 (1940).

$N_2=605$ counts per minute, total time $=60$ minutes. In this time interval 5 coincidences were observed. The expected number of chance coincidences was 5.7. In all, 50 coincidences were recorded in 12.55 hours. The number of chance coincidences to be expected in this same time was 63.1 ± 5.3.

The number of coincidences to be expected if the recoils were due to a gamma-ray was determined by assuming that the efficiency of the multiplier tube was 100 percent and that of the G-M tube was one percent. Since both counters subtended about the same solid angle at the source, the number of coincidences per minute was given by $0.01\ N_2$. In the example above, 333 coincidences per hour should have been observed if the recoils were due to gamma-rays. By similar calculations 3757 coincidences should have been observed during the 12.55 hours while actually 50 were observed. The calculated value is about 80 times the observed number of coincidences. This large difference between the observed and expected coincidence rates rules out the possibility of the recoils being caused by either a 0.45-Mev or a 0.87-Mev gamma-ray. Even though the efficiencies of either tube were considerably smaller than the values assumed, some increase in the coincidence rate over that expected by chance should have been observed.

DISCUSSION

An accurate determination of the maximum recoil energy is made difficult by the fact that the retarding potential curves do not approach the axis very steeply. However, this behavior probably is an inherent difficulty in this type of experiment. Since the recoils have so little energy, it is almost impossible to prepare a target that is truly thin. The fact that the observed maximum recoil energy increased when readings were taken immediately after the heating of the target suggests that the true maximum may be somewhat higher than the observed value. An experiment carried out with the target held at a temperature of several hundred degrees C should remove this difficulty.

The momentum of the recoil nucleus ejected by the emission of a neutrino in the Be^7 decay process is given by

$$p=(1/c)(T^2+mc^2T)^{\frac{1}{2}},$$

where p is the recoil momentum, and m and T, respectively, are the rest mass and kinetic energy of the neutrino. Since the neutrino receives most of the energy, T is very nearly equal to 0.87 Mev. If the rest mass of the neutrino is assumed to be zero, the maximum energy of the recoils is found to be 58 electron volts. Both the Fermi and Konopinski-Uhlenbeck theories for the shape of the continuous beta-ray spectrum require the neutrino rest mass to be zero or, at most, 0.2 that of the electron in order to agree with the observed shape of the high energy part of the curve. A neutrino rest mass of 0.2 that of the electron will lower the maximum recoil energy by only one electron volt. Thus the recoil energy must be measured very accurately for a determination of the neutrino rest mass. Since positive ion work functions may be several electron volts for metals not completely outgassed, the observed recoil energy will be a few electron volts less than the actual value. The value observed in this experiment is from 10 to 15 electron volts lower than the expected value. Part of this discrepancy is due to the positive ion work function of the platinum strip and part is due to the energy lost by the ions in penetrating the layer of gas on the surface of the source.

The fact that no positrons were found confirms the observations of Haxby[5] and collaborators on the Be^7-Li^7 mass difference. The value of 1.02 Mev required for positron emission is considerably higher than the value of 0.87 ± 0.03 Mev given by this group.

It has been shown that the observed recoils were not caused by gamma-rays. Unless some new mechanism for the removal of the energy produced in the Be^7 decay process can be discovered, it must be concluded that the recoils were caused by the emission of a neutrino of nearly zero rest mass.

In conclusion, the author wishes to express his gratitude to Professor S. K. Allison of the University of Chicago for suggesting the use of Be^7 in this experiment and also for many helpful discussions during the experiment. Thanks are also extended Dr. Louis Slotin and the other members of the University of Chicago cyclotron crew for preparing the radioactive material used in this experiment.

Is Space-Time Flat?

WILLIAM BAND
Department of Physics, Yenching University, Peiping, China
(Received February 13, 1942)

Lorentz transformations are developed between relatively accelerated systems, based on the assumption that there exists an inertial set defining absolute acceleration and on the supposition that the accelerated observer uses at each moment the member of this inertial set appropriate to his momentary velocity. The application of this transformation to a planetary observer shows that the system is non-affine; beyond a critical distance events occur in reverse order during half the year and stretch through longer than normal times in the opposite season. Actual appearances at the origin are not affected by this feature, since the velocity of light is reversed when time is reversed, and carries the original frequency unchanged to the observer. Rosen's method of avoiding this non-affine character of flat space is discussed, and shown still to require the existence of an absolute standard of uniformity of motion before the real field theory of gravitation can be maintained. It is not claimed that flat-space theory is false, but that in practice it would be an inconvenient method of description that can hardly be identified with that actually employed in astronomy and physics.

INTRODUCTION

SINCE Einstein's formulation of his theory of gravitation in terms of a Riemannian curved space-time metric, there have been many attempts to incorporate the various advantages of Einstein's theory within the framework of a flat space-time. Perhaps the most ambitious attempt was that of A. N. Whitehead,[1] generalized by G. Temple,[2] which developed a formalism of its own *ab initio*. More recent attempts have been made[3] which seek rather to re-interpret the formalism of Einstein from the "flat-space" point of view. These attempts were apparently stimulated in part by D. C. Miller's observations on ether drift.[4] Now that W. C. Anderson's work[5] has turned the evidence more in favor of the original point of view of Einstein, it would appear desirable to examine more critically the flat-space hypothesis.

The present writer has already published a somewhat feeble protest[6] against the Whitehead theory of absolute acceleration, and now feels it may be worth while to restate this protest in clearer and more precise terms.

[1] A. N. Whitehead, *The Principle of Relativity* (Columbia University Press, 1922).
[2] G. Temple, Proc. Phys. Soc. **36**, 176–193 (1924).
[3] A. Eagle, Phil. Mag. **23**, 694–701 (1929); N. Rosen, Phys. Rev. **57**, 147–155 (1940).
[4] D. C. Miller, Rev. Mod. Phys. **5**, 203–242 (1933).
[5] W. C. Anderson, J. Opt. Soc. Am. **31**, 187–197 (1941).
[6] W. Band, Phil. Mag. **7**, 434–440 (1929).

LORENTZ TRANSFORMATIONS BETWEEN RELATIVELY ACCELERATED OBSERVERS

We shall work from the flat-space point of view. This means we assume the existence of an inertial set of reference systems which can be definitely identified with the "natural" systems of absolutely unaccelerated observers. It also means that we suppose that an accelerated observer S' will, at any instant, use the same flat space-time system as an unaccelerated observer S momentarily at rest with S' at the instant of interest. During his accelerated motion S' employs a reference system actually composed of a succession of the inertial set of systems.

Write down the Lorentz transformations between two members S and S_0 of the inertial set, where S is moving with velocity $\mathbf{v}$ relative to S_0:

$$\mathbf{r}'=\mathbf{r}+k\mathbf{v}t+(k-1)\mathbf{v}(\mathbf{r}\cdot\mathbf{v})/v^2, \qquad (1)$$
$$t'=k(t+\mathbf{r}\cdot\mathbf{v}/c^2).$$

Then S' shall employ the same reference system as that used by S when their velocities coincide. To find the transformation between the displacements in the two systems we may therefore differentiate (1) regarding v as a variable following the motion of S'. This gives the following transformation from S_0 to S'.

$$d\mathbf{r}'=d\mathbf{r}+(k-1)\mathbf{v}(d\mathbf{r}\cdot\mathbf{v})/v^2+k(\mathbf{v}+\mathbf{f}t)dt$$
$$+(k-1)(\mathbf{f}(\mathbf{r}\cdot\mathbf{v})/v^2+\mathbf{v}(\mathbf{r}\cdot\mathbf{f})/v^2)dt, \qquad (2)$$
$$dt'=kdt(1+\mathbf{r}\cdot\mathbf{f}/c^2)+k\mathbf{v}\cdot d\mathbf{r}/c^2.$$

In these relations, $(\mathbf{r}, t)$ is the S measure of the interval between what we may call the act of observation and the observed event, and $\mathbf{f}$ is the S measure of the acceleration of S' at the instant of observation.

LORENTZ TRANSFORMATIONS TO AN OBSERVER REVOLVING IN A CIRCULAR ORBIT

Let S' be an observer revolving in a circle about the origin as center—a model which approximates the terrestrial observer with the sun at the center. Then at any instant we can use (2) to transform from S' to S_0', where S_0' is an observer coinciding with S' at the instant, but at rest with respect to S_0 at the origin. The transformation from S_0' to S_0 is then merely a translation through the radius vector of the orbit at the instant of interest. Thus we have in general, writing R for the radius vector from the origin to S' at the instant:

$$\begin{aligned} d\mathbf{r}' &= d\mathbf{r}_0+(k-1)\mathbf{v}(d\mathbf{r}\cdot\mathbf{v})/v^2+k(\mathbf{v}+\mathbf{f}t)dt \\ &\quad +(k-1)(\mathbf{f}(\mathbf{r}_0\cdot\mathbf{v})/v^2+\mathbf{v}(\mathbf{r}_0\cdot\mathbf{f})/v^2 \\ &\quad -\mathbf{v}(\mathbf{R}\cdot\mathbf{f})/v^2)dt, \qquad (3) \\ dt' &= kdt(1+(\mathbf{r}_0-\mathbf{R})\cdot f/c^2)+k\mathbf{v}\cdot d\mathbf{r}_0/c^2. \end{aligned}$$

Here $\mathbf{r}_0$ is the radius vector from the center to the point of interest where the differentials are being measured; also we have used the fact that $\mathbf{v}$ and $\mathbf{R}$ are mutually perpendicular. We may further write

$$\begin{aligned} &\mathbf{R}=R(\cos wt\mathbf{i}_1+\sin wt\mathbf{i}_2), \\ &\mathbf{v}=-wR(\sin wt\mathbf{i}_1-\cos wt\mathbf{i}_2), \qquad (4) \\ &\mathbf{f}=-w^2\mathbf{R}, \quad v=wR. \end{aligned}$$

The relations (4) then permit us to write down the correct transformation (3) at any desired phase of the motion of S'.

To appreciate the meaning of these transformations we consider a special case, namely, when the point of interest or the observed event is on the same radius as the observer S', at the instant of interest. Thus we may write

$$\mathbf{r}_0=r_0\mathbf{i}_1, \quad \mathbf{R}=R\mathbf{i}_1, \quad \mathbf{v}=wR\mathbf{i}_2, \quad \mathbf{f}=-w^2R\mathbf{i}_1. \qquad (5)$$

Substituting these special values into (3), we obtain after some simple reductions:

$$\begin{aligned} d\mathbf{r}' &= d\mathbf{r}_0+(k-1)dy_0i_2-k(w^2Rt\mathbf{i}_1+\mathbf{v})dt \\ &\quad -(k-1)(r_0-R)w\mathbf{i}_2dt, \qquad (6) \\ dt' &= kdt(1-(r_0-R)w^2R/c^2)+kvdy_0/c^2. \end{aligned}$$

FLAT SYSTEM OF REVOLVING OBSERVER IS NON-AFFINE

A glance at the second of Eqs. (6) will show that there exists a point where time as determined by S' will "stand still." Thus events occurring at a given point, dy_0 zero, at a distance c^2/w^2R^2 from S', all occur at the same time, $dt'=0$, at least while the radius from the center to S' sweeps past the proper position. In the opposite phase of the motion of S' these events will stretch double the time dt. At points beyond this distance dt' becomes negative, which means that the same event will be assigned more than one definite time coordinate by the S' system.

For terrestrial observers, using the values of w and R for the earth's orbit, the critical distance is about 10^{21} cm, well within the galactic system!

This does not mean, however, that according to flat-space theory, events beyond the critical distance ought actually to *appear* to S' as if they took place in the reverse order during part of the year, and caught up with themselves again during the opposite season. The relations (6) are pure extrapolations. The actual appearance of events at great distances from the observer depends upon the propagation of light; and this is the same for every one of the family of inertial systems used by S' throughout his motion. The propagation of light is unaffected by the extrapolations involved in (6).

What happens in detail is this: the calculated speed of light, in the S' system, becomes infinite at the critical moment where dt' vanishes, and negative where dt' is negative, so the propagation continues blissfully ignorant of the peculiar antics of t'. The period of the light waves, also, is not influenced by the variable ratio between dt' and dt shown in (6), so that in spite of apparent red and blue shifts which one might expect from a superficial reading of (6), the theory actually does not predict such a phenomenon.

These assertions are easily checked analytically. Write

$$d\mathbf{r}_0=-cdt\mathbf{i}_1 \qquad (7)$$

for a light ray traveling towards the center. Then (6) become, if for simplicity we take $t=0$ (we are interested in the velocity "now"), simply

$$\begin{aligned} &d\mathbf{r}'/dt=-c\mathbf{i}_1-(R-r_0+kr_0)w\mathbf{i}_2, \\ &dt'/dt=k(1-(r_0-R)w^2R/c^2). \end{aligned} \qquad (8)$$

Since we are interested in values of r_0 of the order 10^{21} cm, we can neglect R, and write for the velocity of light for S'

$$\mathbf{c}'_r = d\mathbf{r}'/dt' = -c(\mathbf{i}_1 - krw\mathbf{i}_2/c)/(1 - rw^2R/c^2)k. \quad (9)$$

Even without the approximation, comparison with (6) shows that where dt' vanishes, c' becomes infinite, etc. Equation (9) it must be remembered, is the velocity of light that will be assigned by S' to the propagation at distance $\mathbf{r}$; the velocity he would obtain in his own neighborhood would be given by (8) with $r_0 = R$, and this becomes

$$\mathbf{c}'_0 = -c(\mathbf{i}_1/k - wR\mathbf{i}_2/c). \quad (10)$$

This includes the usual aberration term, and presents nothing unusual: its magnitude is exactly c.

To check the invariance of frequency it would be necessary to develop the quadratic expression ds^2 in terms of dr' and dt', by making use of (6). It seems unnecessary to undertake the tedious algebra required for the proof; it is already sufficiently obvious that the observed frequencies will remain normal during the motion of S' because at each instant he is using one of the inertial set relative to which only the normal Doppler shift will be present.

We do not doubt, therefore, that the flat-space theory can be made to fit the facts of observation, at least roughly. But when the observer S' insists on projecting his flat systems at each instant by extrapolation beyond his immediate neighborhood, he runs into all kinds of fantastic inconveniences. We do not assert that S' cannot perform such extrapolations, but in practice he does not. The terrestrial observer in practice adopts a static system in which the velocity of light is a constant everywhere, or at most a function of the gravitational potential; it certainly is not a function of the acceleration of the observer in the way indicated in (9). And most serious of all, the terrestrial observer makes every effort to assign a definite set of coordinates to every event, and is not willing to suppose this to be fundamentally impossible—as it would be if his space-time were non-affine.

ROSEN'S AFFINE FLAT SPACE-TIME

The only way to retain flat space-time and to avoid the non-affine character of the extrapolated local flat systems of the planetary observer, seems to be that suggested by Rosen.[3] This involves accepting for the planetary observer a different value for the invariant interval from that used above. Thus, suppose that first we set up the Riemannian metric of general relativity by means of which coordinates can be assigned everywhere without ambiguity; and accept these assigned coordinates but define a new invariant interval in terms of them which is simply a Euclidean quadratic form. Since a "flat" quadratic form can never become curved by coordinate transformations, this procedure succeeds in establishing a definite set of flat reference systems which are affine everywhere. It now becomes a question of whether the Riemannian or the Rosen quadratic form is "really" the physical interval in space-time.

To see clearly the contrast between Rosen's procedure and that used above for finding the flat system of a planetary observer, we note that on Rosen's method the accelerated observer S' assigns different coordinates to events from those assigned by an unaccelerated observer S who is momentarily coincident and at rest with S'; but the interval used by S' may be the same function of his new coordinates as the function used by S in terms of the S coordinates. Acceleration thus corresponds rather to a strain than a transformation of the reference system. Whether it is intended that all other physical entities which are functions of position should undergo the same strain—i.e., remain the same functions of the new coordinates—is not clear.

From a formal point of view Rosen's method has the following advantage. We first agree to a convention, that if a coordinate transformation is effected in the Riemannian system, the same coordinate transformation is to be carried out in the Rosen flat system, so that we *always* have the same coordinates assigned everywhere by the two systems. It follows from this that tensor character is imparted to certain quantities which could not be tensors otherwise. Moreover, the Riemannian metric tensor can then be regarded instead as a gravitational field tensor, and the formalism of the Einstein theory of gravitation can be carried over unchanged into the new point of view, and made to give the same observational results.

Now the agreed convention regarding coordinate transformations has one important consequence that was apparently overlooked. It is perfectly easy in the Riemannian system to transform the time-axis into any geodesic—for example, the history of the planetary observer. The geodesic behavior of the central mass is not thereby altered. But according to Rosen's agreed convention, the same transformation must be effected in the flat space, which of course means that the history of our planetary observer also becomes the new time-axis in the flat space; but the motion of the central mass then has to be explained in terms of immense forces, which analytically are provided for by the Riemannian fundamental tensor components.

In physics we are familiar with this kind of situation, and regard such forces as fictitious; it seems that the same attitude has to be adopted here from the point of view of Rosen's theory. Yet it is one of the points made by Rosen, that the gravitational field is restored to its physical reality by the flat-space theory. It is difficult to see how we are to reconcile these two viewpoints; for if the field given by the Riemannian fundamental tensor is fictitious in one system, why should it be real in some other systems? And it is not clear which particular system could be chosen unless we are perfectly sure that the cosmological field actually defines a standard of absolute zero acceleration—a rather dangerous assumption in the present state of cosmological knowledge.

The adoption of Rosen's method, therefore, would logically involve a fundamental departure from the general principle of relativity, if we wish to use it as a way of restoring the field theory of gravitation: an absolute standard of uniformity of motion has to be postulated just as in the straightforward restricted relativity theory and in Newtonian dynamics. If we are unwilling to make this postulate, then the gravitational field loses its reality even in the Rosen flat system, so that we might as well go right over to the general relativity method!

CONCLUSION

It has not been claimed that flat space-time theory is actually false. Locally it can make no difference whether we regard our coordinate system as flat or curved. Differences arise when the observer wishes to assign coordinates to events outside his immediate experience, which he regards as the "causes" of local appearances —the sources of the light signals received at the observer's origin. It would be meaningless to discuss the truth or falsity of such coordinate assignments; convenience and self-consistency can be the only criteria beyond questions of observational accuracy which do not concern the pure theorist.

The difference between the Rosen flat space and the Riemannian curved space is however real, even at the observer's locality. The status of Rosen's flat space in the general scheme of relativity theory will be discussed in detail in another paper. Here we have simply pointed out that if any flat-space point of view is adopted, including Rosen's, we must logically assume the existence of a standard of absolute uniformity of motion, and refuse to permit a terrestrial—or any other planetary—observer to regard his own history as a suitable time-axis for a coordinate system. Yet the Rosen method appears to be the only practical escape, short of general relativity, from the non-affine character of extrapolated local flat systems based upon tangency to the Riemannian space at any point.

If any conclusion can be drawn by mere argument, we might here assert that a non-affine system is extraordinarily useless, and an absolute standard of uniformity remarkably elusive; complete freedom from these troubles can only be assured by a thoroughly general relativistic theory.

Comparison Spaces in General Relativity

WILLIAM BAND
Department of Physics, Yenching University, Peiping, China
(Received February 13, 1942)

A physical interpretation is given of the mathematical theorem that a Riemannian space can be defined by means of the system of local tangent flat spaces. This leads naturally to an elucidation of the status of Rosen's flat space in the general relativity theory. Comparison flat spaces can be chosen arbitrarily, and if taken as giving the metric of space time lead to different arbitrary values of ether drift. In particular, the flat-space tangent to the Riemannian space along the history of the observer (at the origin) is locally equivalent with the Riemannian space, and no ether drift would be involved in using it in place of the Riemannian space as a method of extrapolating measurements to great distances. It is further shown that the formal simplifications achieved by introducing the comparison metric do not depend on its flatness. A *de Sitter* type of isotropic empty space is introduced by means of which the distribution and laws of motion of matter can be expressed in terms of the differences between actual space containing matter and the empty comparison space. Comparison spaces in general are essentially ideal, and can be introduced to bring out the non-ideal characteristics of actual space.

INTRODUCTION

IT was shown by Rosen[1] that by arbitrarily introducing an Euclidean quadratic form in the coordinates side by side with the Riemannian metric of the Einstein theory, a formal simplification of important equations of general relativity could be secured.

Rosen further pointed out the possibility of abandoning the geometrical interpretation of the Riemannian metric in favor of the Euclidean form as the natural space-time metric of an observer in a gravitational field.[2] The field potential would be described in terms of the Riemannian fundamental tensor. The rays of light would be given by null geodesics in the Riemannian field, which would thus behave as a medium with a refractive index depending on the gravitational potential. An ether drag[3] caused by motion through the field is then to be expected, which circumstance was claimed to favor the flat-space point of view.

Since Rosen's work, Anderson[4] has published his measurements of the velocity of light, in which the greatest possible drag variation in six months was less than the mean daily variation. As his measurements are apparently the most precise to date, it would appear that the flat-space point of view has lost observational support in this respect.

It should perhaps be pointed out in passing that the argument would not be affected by the possible existence of secular changes in the velocity of light such as those discussed by Birge,[5] since small variations of gravitational potential in the local stellar cluster would suffice to account for these on either theory.

Certain fundamental theoretical difficulties involved in the flat-space point of view have been discussed elsewhere.[6] In the present paper we discuss the status of Rosen's flat space within the scheme of general relativity, and point out how the formal advantages of Rosen's method are independent of the flatness of the comparison space.

RIEMANNIAN SPACE AS A SYSTEM OF LOCAL SPACES

It is known[7] that a complete "curved" space can be built up from a system of local spaces by means of linear connections; also that the Riemannian space can be defined by the system of local tangent "flat" spaces.[8] From the point of view of physics, these mathematical theorems can be described as follows.

[1] N. Rosen, Phys. Rev. **57**, 147–150 (1940).
[2] N. Rosen, Phys. Rev. **57**, 150–154 (1940).
[3] N. Rosen, Phys. Rev. **57**, 154–155 (1940).
[4] W. C. Anderson, J. Opt. Soc. Am. **31**, 187–197 (1941).
[5] R. T. Birge, Nature **134**, 771 (1934).
[6] W. Band, Phys. Rev. **61**, 668 (1942).
[7] D. J. Struik, *Theory of Linear Connections* (Springer, 1934).
[8] O. Veblen, *Projective Relativitätstheorie* (Springer, 1933).

A freely falling observer finds the gravitational field locally absent, and his reference system locally flat. Let him employ unit reference vectors $\mathbf{i}^\alpha$, where[9]

$$\mathbf{i}^\alpha \cdot \mathbf{i}^\beta = \delta_{\alpha\beta} = 0,\ \alpha \neq \beta\,; \quad = 1,\ \alpha = \beta = 0\,; \quad = -1,\ \alpha = \beta \neq 0. \tag{1}$$

Any attempts by an observer to make measurements outside of his own immediate locality are to be considered extrapolations; direct measurements are to be confined to his own neighborhood. The principle of connectivity, however, states that it is possible for any observer S to compare with his own, the unit reference vectors used nearly simultaneously by any other observer S' at a position not too far removed from S at the time of comparison.

If one now imagines a system of free observers, one to every small four-dimensional region, one can at once set up the fundamental equations of differential geometry:

$$d\mathbf{i}^\alpha = \Gamma^\alpha_{\mu\nu} dy^\nu \mathbf{i}^\mu, \tag{2}$$

where dy^ν are the components of the position of S' against S:

$$\mathbf{SS}' = dy^\alpha \mathbf{i}^\alpha. \tag{3}$$

Since the members of this system are all free observers, the system obtained from (2) is everywhere flat, and the linear connections must satisfy the condition

$$B^\epsilon_{\mu\nu\sigma} = \Gamma^\alpha_{\mu\sigma}\Gamma^\epsilon_{\alpha\nu} - \Gamma^\alpha_{\mu\nu}\Gamma^\epsilon_{\alpha\sigma} + \frac{\partial}{\partial x^\nu}\Gamma^\epsilon_{\mu\sigma} - \frac{\partial}{\partial x^\sigma}\Gamma^\epsilon_{\mu\nu} = 0. \tag{4}$$

It is obvious that the free observers cannot in fact all be permanent members of the system, for in general two free observers will be near neighbors only momentarily. This is the physical language for the mathematical statement that the system of coordinates set up will be non-affine. In practice we do not go on re-creating new free observers for each small four-dimensional element of space-time, but we set up, in principle, a system of observers which are supported in such a way as to be permanent members of the system whose origin is set permanently on the first-chosen free observer.

It is not necessary to specify exactly the system of observers beyond the single requirement that their relative motions shall be such as to maintain mutual neighborliness! Such a system, while impracticable, is conceivable, and hence acceptable as the basis of extrapolations from the origin. The principle of connectivity applied to such a system permits the relations

$$d\mathbf{e}^\alpha = \left\{ {\mu \atop \alpha\nu} \right\} dx^\nu \mathbf{e}^\mu, \tag{5}$$

where $\mathbf{e}^\mu$ are the unit vectors for any supported observer, and dx are the components of the position of S against S':

$$\mathbf{SS}' = dx^\alpha \mathbf{e}^\alpha. \tag{6}$$

By the manner of its definition, the system is affine, so that

$$\left\{ {\mu \atop \alpha\nu} \right\} = \left\{ {\mu \atop \nu\alpha} \right\}, \tag{7}$$

but not in general flat because of the "supports" and local presence of gravitational fields.

It will now be conceivable for any one of the supported observers to compare his unit reference vectors with those of the appropriate member of the system of free observers. The relative acceleration between them will be equivalent to a linear transformation, and we shall expect the relation:

$$\mathbf{e}^\mu = \phi^\alpha{}_\mu \mathbf{i}^\alpha, \tag{8}$$

where the dyadic components $\phi^\alpha{}_\mu$ can be found in every small four-dimensional region. It will be assumed possible to choose the system of free observers in such a way that $\phi^\alpha{}_\mu$ vary continuously from region to region everywhere, and therefore are well-behaved functions of position in the affine x space of the supported observers.

Comparing (3) with (6), noting that the intervals $\mathbf{SS}'$ can be chosen identical in the two relations, we see that

$$dx^\nu \mathbf{e}^\nu = dy^\nu \mathbf{i}^\nu \tag{9}$$

and from (8)

$$dy^\mu = \phi^\mu{}_\nu dx^\nu. \tag{10}$$

This constitutes a linear transformation between the non-affine flat y space and the affine curved x space.

The metrics of the two spaces are given by their unit reference vectors. Thus the quadratic intervals are, respectively,

$$ds^2 = \delta_{\mu\nu} dy^\mu dy^\nu, \text{ where } \mathbf{ds} = dy^\nu \mathbf{i}^\nu, \tag{11}$$

and

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu, \text{ where } \mathbf{ds} = dx^\mu \mathbf{e}^\mu, \tag{12}$$

and

$$g_{\mu\nu} = \mathbf{e}^\mu \cdot \mathbf{e}^\nu = \delta_{\alpha\beta}\phi^\alpha{}_\mu \phi^\beta{}_\nu. \tag{13}$$

[9] W. Band, Am. J. Phys. **8**, 162–164 (1940).

It should be remarked that the above transformation relations between flat and curved metrics are possible only because the flat metric is non-affine; the Eqs. (10), for example, are not integrable. It is of interest also to note that the relations (13) signify that whereas the metric of the curved space is determined by the transformation (8), the converse is not true; there are many possible systems of free observers which would lead to the same curved metric with a given single free observer as permanent origin.

COMPARISON FLAT SPACES

If Eqs. (10) are used in the linear connection (2) we obtain

$$d\mathbf{i}^{\alpha} = \Lambda^{\alpha}_{\mu\nu} dx^{\nu} \mathbf{i}^{\mu}, \tag{14}$$

where

$$\Lambda^{\mu}_{\alpha\nu} = \phi^{\sigma}_{\nu} \Gamma^{\mu}_{\alpha\sigma}. \tag{15}$$

Now the relations (14) constitute an alternative linear connection in x space for comparison with (5); since x space is already affine the coefficients of (14) must satisfy

$$\Lambda^{\mu}_{\alpha\nu} = \Lambda^{\mu}_{\nu\alpha}.$$

Moreover, since the reference system $\mathbf{i}^{\alpha}$ is everywhere flat

$$\Lambda^{\alpha}_{\mu\sigma}\Lambda^{\epsilon}_{\alpha\nu} - \Lambda^{\alpha}_{\mu\nu}\Lambda^{\epsilon}_{\alpha\sigma} + \frac{\partial}{\partial x^{\nu}}\Lambda^{\epsilon}_{\mu\sigma} - \frac{\partial}{\partial x^{\sigma}}\Lambda^{\epsilon}_{\mu\nu} = 0. \tag{16}$$

These last two equations are not inconsistent with (4) nor with the non-affine condition in y space, namely

$$\Gamma^{\mu}_{\alpha\nu} \neq \Gamma^{\mu}_{\nu\alpha}. \tag{17}$$

The differences between the linear connection coefficients in the two spaces can be expressed in terms of the components ϕ^{α}_{μ}. Thus, let $\phi^{*\mu}_{\alpha}$ be the components of the reciprocal conjugate dyadic, so that (8) solves in the form:

$$\mathbf{i}^{\alpha} = \phi^{*\mu}_{\alpha} \mathbf{e}^{\mu}. \tag{18}$$

Then it is easily shown that

$$d\mathbf{i}^{\alpha} = (\phi^{*\mu}_{\alpha;\gamma} + \{{}^{\sigma}_{\alpha\gamma}\}\phi^{*\mu}_{\sigma})\mathbf{e}^{\mu} dx^{\gamma}, \tag{19}$$

where $\phi^{*\mu}_{\alpha;\gamma}$ is the set of intrinsic $\{\ \}$-derivatives of $\phi^{*\mu}_{\alpha}$. By comparison of (19) with (14) and by use of (8) on the right of (19) we obtain

$$\Delta^{\alpha}_{\mu\nu} \equiv \{{}^{\alpha}_{\mu\nu}\} - \Lambda^{\alpha}_{\mu\nu} = \phi^{*\sigma}_{\mu;\nu}\phi^{\alpha}_{\sigma}. \tag{20}$$

The analogous reasoning starting directly from (8) instead of (18) leads to the alternative expression

$$\Delta^{\alpha}_{\mu\nu} = \phi^{\sigma}_{\mu,\nu}\phi^{*\alpha}_{\sigma}, \tag{21}$$

where $\phi^{\sigma}_{\mu,\nu}$ are the intrinsic Λ derivatives of ϕ^{σ}_{μ}.

The invariant interval associated with (14) is evidently

$$d\boldsymbol{\sigma} = dx^{\mu}\mathbf{i}^{\mu}, \tag{22}$$

which will be called the comparison interval with respect to the true interval $d\mathbf{s}$ given by (12). To permit transformations to different flat systems a more general notation than (11) is desirable for the comparison metric, which will, therefore, be written in the form

$$d\sigma^2 = \gamma_{\mu\nu} dx^{\mu} dx^{\nu}. \tag{23}$$

Here

$$\gamma_{\mu\nu} = \mathbf{i}^{\mu} \cdot \mathbf{i}^{\nu}, \tag{24}$$

and (13) is replaced by

$$g_{\mu\nu} = \gamma_{\alpha\beta}\phi^{\alpha}{}_{\mu}\phi^{\beta}{}_{\nu}. \tag{25}$$

Transformations of coordinates will leave invariant both $d\sigma$ and ds, while $\phi^{\alpha}{}_{\mu}$ will transform as tensor components.

Given a particular Riemannian metric, the choice of a flat comparison metric is still undetermined. For example, we may choose $\gamma_{\mu\nu}$ equal to $g_{\mu\nu}$ at the origin, so that the flat space is tangent to the Riemannian space at the origin. This would require, at the origin

$$\phi^{\alpha}{}_{\beta} = \delta^{\alpha}{}_{\beta}, \tag{26}$$

where $\delta^{\alpha}{}_{\beta}$ is the ordinary δ symbol [not the same components as those introduced in (1) and used in (13)]. With this tangent comparison space we derive from (20) and (21)

$$\Delta^{\alpha}_{\mu\nu} = \phi^{*\alpha}_{\mu;\nu} = \phi^{\alpha}_{\mu,\nu}. \tag{27}$$

There will be no distinction between the two spaces in the neighborhood of the observer at the origin, and they will merely represent two different possible methods of extrapolating measurements at great distances.

If on the other hand the Riemannian space tends towards flatness at great distances, it is equally possible to set up a flat comparison

space which is tangent to the Riemannian space at infinity. This would give the flat space suggested by Rosen,[1] and there will be a definite distinction between the two spaces in the neighborhood of the observer at the origin. There is no necessity to make any particular choice, so far as formal convenience is concerned. In fact Rosen's choice would become impossible were the Riemannian space not tending towards flatness at infinity, and we should have to be satisfied with tangency at any arbitrarily chosen point.

Since the Riemannian space and the comparison space are based on the same coordinate system, transformations of coordinates take place in both systems simultaneously and their common point of tangency is invariant. The set $\phi^{\alpha}{}_{\mu}$ transforms as a tensor, and hence, through (21) the differences between the two linear connection coefficients also transform as a tensor. The formal simplifications obtained by the use of the Rosen flat space are consequences of any of the choices of flat comparison spaces here discussed, and do not depend upon the point of tangency between the two spaces.

EQUATIONS OF MOTION

Since the gravitational field is absent in the local flat space, the observer's own track will be a straight line in terms of the local space:

$$0=d^2\mathbf{s}=d(dy^{\mu}\mathbf{i}^{\mu})=\mathbf{i}^{\alpha}(d^2y^{\alpha}+\Gamma^{\alpha}_{\mu\nu}dy^{\mu}dy^{\nu}). \quad (28)$$

In terms of the comparison space, the equation of a straight line would be rather

$$0=d^2\boldsymbol{\sigma}=d(dx^{\mu}\mathbf{i}^{\mu})=\mathbf{i}^{\alpha}(d^2x^{\alpha}+\Lambda^{\alpha}_{\mu\nu}dx^{\mu}dx^{\nu}). \quad (29)$$

The actual equations of motion in terms of the x coordinates are obtained by going over from (28) to the Riemannian space:

$$0=d^2\mathbf{s}=d(dx^{\mu}\mathbf{e}^{\mu})=\mathbf{e}^{\alpha}(d^2x^{\alpha}+\{^{\alpha}_{\mu\nu}\}dx^{\mu}dx^{\nu}), \quad (30)$$

which, by (20), can be written as

$$d^2x^{\alpha}+\Lambda^{\alpha}_{\mu\nu}dx^{\mu}dx^{\nu}=-\Delta^{\alpha}_{\mu\nu}dx^{\mu}dx^{\nu}. \quad (31)$$

Comparison between (29) and (31) shows that, if the observer makes use of the comparison flat space, the true equations of motion will appear as if a gravitational field were present disturbing the motion. The force depends only upon the connection differences; but since the actual choice of comparison space is not prescribed, the force is actually arbitrary. If the comparison space is chosen tangent to the Riemannian space along the history of the observer at the origin, then the connection differences, and hence the apparent force, will permanently vanish in the immediate neighborhood of the origin. If the comparison space is tangent to the Riemannian space at infinity, the apparent force will approximate the force of Newtonian theory. But none of these choices is compulsory, and no preference should be given to any special value of the force in a claim to "reality."

NON-EXISTENCE OF AN ETHER DRAG

Consider two momentarily coincident planetary observers with uniform relative velocity. Since their local flat spaces are tangent with their respective curved systems in their own (common) neighborhood, the transformation between their curved spaces will be the Lorentz transformation between their local flat spaces. The coefficients of the quadratic forms are functions only of the gravitational potentials and these are the same for the two observers. The Lorentz transformation thus leaves unchanged the coefficients of the quadratic form.[10] If we take

$$ds^2=c^2(1+2\phi/c^2)dt^2-(1-2\phi/c^2)dr^2, \quad (32)$$

the transformation will be approximately

$$dx=k'(dx'+vdt'), \quad dt=k'(dt'+vdx'/c'^2), \quad (33)$$

where

$$k'=(1-v^2/c'^2)^{-\frac{1}{2}}, \quad \text{and} \quad c'=c(1+2\phi/c^2). \quad (34)$$

In terms of x', t', we have, of course,

$$ds^2=c^2(1+2\phi/c^2)dt'^2-(1-2\phi/c^2)dr'^2. \quad (35)$$

The velocity of light on the two systems is the same, and no "ether drag" can be expected.

If we use the Rosen comparison space we may write

$$d\sigma^2=c^2dt^2-dr^2, \quad (36)$$

where c is the velocity of light in regions remote from matter, or at infinity in the Riemannian space. If we arbitrarily assume that the correct transformation between the two systems leaves

[10] The writer wishes to thank Dr. Rosen for a discussion of this point.

the coefficients of (36) unchanged, then we shall have to use the ordinary Lorentz transformations like (33) and (34) with the unprimed symbols. The application of this to (32) leads to

$$ds^2=c^2dt'^2(1+2\phi'/c^2)+8\phi k^2vdx'dt' -dx'^2(1-2\phi'/c^2), \quad (37)$$

where

$$\phi'=\phi(1+v^2/c^2)k^2. \quad (38)$$

The velocity of light, given by $ds=0$ in (37) is easily shown to be, when terms in $(v/c)^2$ are neglected,

$$c(1+2\phi/c^2)(1+4\phi v/c^3). \quad (39)$$

This gives the ether drag coefficient $-4\phi v/c^3$ as in Rosen's work. The result is the same as if we regarded the gravitational field relative to the metric of (36) as a medium of refractive index $(1+2\phi/c^2)$.

If instead of Rosen's particular comparison space we were to choose some other flat space, and arbitrarily assume again that the coefficients of the quadratic form shall remain unchanged by transformations between the two observers, we should of course derive different expressions for the gravitational potential and the ether drag coefficient. Since a change in the velocity of light is a question of fact rather than of mere convenience, we cannot claim that the different assumptions are equivalent. From the general relativity point of view which we are here developing, the error is in assuming that the correct transformations will leave unchanged the coefficients in the flat quadratic forms. There is only one correct transformation, namely (33) and (34), whatever comparison space we choose; and it is the coefficients of the flat quadratic forms which must change, not those of (32).

Stated rather differently, the fundamental point at issue as between the present point of view and the flat point of view suggested by Rosen, is this; whether we accept as absolute constant the actual velocity of light at the point of interest, or whether only its value at some arbitrarily assigned point—say at infinity—is to remain constant during transformations at the point of interest; whether the actual transformation between two observers at a given point is determined by conditions at the point or by conditions at infinity, or some other arbitrarily chosen point.

ISOTROPIC COMPARISON SPACES

Let us introduce a comparison metric

$$d\sigma^2=\gamma_{\mu\nu}dx^\mu dx^\nu \quad (40)$$

in the same coordinates as the Riemannian space, where now however the tensor $\gamma_{\mu\nu}$ does not satisfy the conditions for flatness. Also write $\Lambda^\alpha_{\mu\nu}$ for the linear connection or Christoffel symbols in the γ's; but do not require them to satisfy (16). Retain the notation

$$\Delta^\alpha_{\mu\nu}=\left\{{\alpha \atop \mu\nu}\right\}-\Lambda^\alpha_{\mu\nu} \quad (41)$$

for the differences between the Christoffel symbols. Then it is easy to prove that when $H_{\mu\nu}$ is any tensor

$$H_{\mu\nu;\,\sigma}=H_{\mu\nu,\,\sigma}-\Delta^\alpha_{\mu\sigma}H_{\alpha\nu}-\Delta^\alpha_{\nu\sigma}H_{\mu\alpha}, \quad (42)$$

where again $;\sigma$ means intrinsic g differentiation, and $,\sigma$ means intrinsic γ differentiation. In particular

$$\Delta^\sigma_{\mu\nu}=\tfrac{1}{2}g^{\alpha\sigma}(g_{\mu\alpha,\,\nu}+g_{\nu\alpha,\,\mu}-g_{\mu\nu,\,\alpha}) \quad (43)$$

and in general, as in Rosen's work, γ differentiation can be substituted for ordinary differentiation, and $\Delta^\alpha_{\mu\nu}$ for $\left\{{\alpha \atop \mu\nu}\right\}$ in any first-order differential tensor equation originally expressed in terms of the Riemannian space. The flatness of the comparison metric is not a condition for this result. Proceeding to second-order differential equations, we find that the difference between the two expressions is given by the above substitution. Thus if $R_{\mu\nu}$ and $P_{\mu\nu}$ are the contracted Riemann-Christoffel tensors in the original and comparison spaces, respectively, their difference is given simply by

$$R_{\mu\nu}-P_{\mu\nu}=\Delta^\alpha_{\alpha\mu,\,\nu}-\Delta^\alpha_{\mu\nu,\,\alpha}+\Delta^\alpha_{\beta\mu}\Delta^\beta_{\alpha\nu}-\Delta^\alpha_{\alpha\beta}\Delta^\beta_{\mu\nu}. \quad (44)$$

This is a direct corollary of a theorem given by Levi-Civita.[11]

Referring now to Rosen's first paper,[1] we may write in place of his Eq. (3) the corresponding relation in a *de Sitter* type of world[12]

$$G_{\mu\nu}=R_{\mu\nu}-\tfrac{1}{2}g_{\mu\nu}(R-2\lambda). \quad (45)$$

If for the comparison metric we adopt the *de Sitter* metric for an empty world, the corresponding expression in this space is zero. Hence, $G_{\mu\nu}$ is

[11] T. Levi-Civita, *Absolute Differential Calculus* (Blackie, 1927), Chapter 8, §3.

[12] A. S. Eddington, *Mathematical Theory of Relativity* (Cambridge, 1924), Chapter 4, §54 (54–71).

also the difference between the corresponding quantities, and the substitutions used by Rosen in his §3 Eq. (11) can be carried over into the present argument. The introduction of the *de Sitter* comparison space instead of a flat space makes no essential difference to the argument.

We can also prove that, instead of (43), we could write

$$\Delta^{\sigma}_{\mu\nu}=\tfrac{1}{2}\gamma^{\alpha\sigma}(\gamma_{\mu\alpha;\nu}+\gamma_{\nu\alpha;\mu}-\gamma_{\mu\nu;\alpha}) \tag{46}$$

and in consequence obtain in place of (44) the alternative form

$$R_{\mu\nu}-P_{\mu\nu}=\Delta^{\alpha}_{\alpha\mu;\nu}-\Delta^{\alpha}_{\mu\nu;\alpha}-\Delta^{\alpha}_{\beta\mu}\Delta^{\beta}_{\alpha\nu}+\Delta^{\alpha}_{\alpha\beta}\Delta^{\beta}_{\mu\nu}. \tag{47}$$

Adding (44) and (47) we obtain

$$R_{\mu\nu}-P_{\mu\nu}=\tfrac{1}{2}(\Delta^{\alpha}_{\alpha\mu;\nu}+\Delta^{\alpha}_{\alpha\mu,\nu}-\Delta^{\alpha}_{\mu\nu;\alpha}-\Delta^{\alpha}_{\mu\nu,\alpha}). \tag{48}$$

This can be expressed approximately in terms of the differences between the two metric tensors. Thus if we write

$$h_{\mu\nu}=g_{\mu\nu}-\gamma_{\mu\nu}, \tag{49}$$

we can express (43) and (46) in the forms

$$\begin{aligned}\Delta^{\sigma}_{\mu\nu}&=\tfrac{1}{2}g^{\alpha\sigma}(h_{\mu\alpha,\nu}+h_{\nu\alpha,\mu}-h_{\mu\nu,\alpha})\\&=\tfrac{1}{2}\gamma^{\alpha\sigma}(h_{\mu\alpha;\nu}+h_{\nu\alpha;\mu}-h_{\mu\nu;\alpha}).\end{aligned} \tag{50}$$

Using the first of these in the g derivatives and the second in the γ derivatives in (48), we are led to an expression which, on neglect of products of h terms, becomes approximately

$$R_{\mu\nu}-P_{\mu\nu}$$
$$=\tfrac{1}{2}\gamma^{\alpha\beta}\left(\frac{\partial^2 h_{\alpha\beta}}{\partial x^{\mu}\partial x^{\nu}}+\frac{\partial^2 h_{\mu\nu}}{\partial x^{\alpha}\partial x^{\beta}}-\frac{\partial^2 h_{\mu\beta}}{\partial x^{\nu}\partial x^{\alpha}}-\frac{\partial^2 h_{\nu\alpha}}{\partial x^{\mu}\partial x^{\beta}}\right). \tag{51}$$

At this point we connect with the reasoning given by Eddington, reference (11) §46. Our Eq. (51) is essentially the analogue of Eddington's (46–3) which refers to a space which is flat when empty. Our $h_{\mu\nu}$ are thus equivalent with his $g_{\mu\nu}$ and the differences $R_{\mu\nu}-P_{\mu\nu}$ take the place of the contracted $R-C$ tensor in Eddington's equation. Following his argument, we therefore find that the differences are given by the density of a continuous distribution of matter.

In general we may summarize this reasoning by asserting that we may choose any kind of space whatever for comparison with the actual space. In particular, we have chosen to compare actual space regarded as containing a static distribution of matter with an ideally empty isotropic space of the *de Sitter* variety; we have found that the distribution and laws of motion of matter can be expressed in terms of the differences between the two spaces. In a similar manner, we might choose to compare an actual space containing an admittedly non-static distribution of matter with an ideal space containing the same mean density of matter in a static distribution. Different comparisons may be convenient for different purposes, and the tensor analysis is capable of handling any of them. Merely because in this way we achieve some kind of formal simplification of the analysis is not a valid reason for regarding any one comparison space as in any sense "actual"; they are essentially ideal, and are introduced merely to bring out the non-ideal characteristics of the actual space.

Total Secondary Electron Emission from Thin Films of Sodium on Tungsten*

KENNETH G. MCKAY†
George Eastman Laboratories of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received April 6, 1942)

The secondary emission yield has been determined for thin films of sodium on a polycrystalline tungsten base and compared with that obtained for a clean tungsten target over a range of primary electron energies of 100 to 1200 volts. The secondary emission yield showed a systematic increase as the work function of the surface was decreased by the addition of sodium. Measurements made as sodium was being evaporated off the tungsten showed that at no time did the secondary emission yield fall below that of clean tungsten. The work function was increased by forming an air film on a clean tungsten surface and the secondary emission was shown to decrease. This variation of secondary emission is in agreement with that found by other experimenters and predicted theoretically.

INTRODUCTION

FOR a complete understanding of the phenomenon of secondary emission, several vital experimental facts must be determined definitely. One of these is the dependence of secondary emission on the work function of the emitting surface. Experimental evidence has been produced to show that there is a definite systematic relation between secondary emission and work function[1–4] while conflicting evidence[5] indicates no such relation. The present investigation was undertaken to deal with this problem, with good vacuum technique and well outgassed constituents so that the surface conditions could be carefully controlled. The base metal of the target had to be such that it could be thoroughly cleaned and outgassed before applying a thin film of the impurity metal. For that reason, a flat ribbon tungsten was used. This could be heated electrically to sufficiently high temperatures to outgas it and to ensure that no contaminating film of any gas remained on the surface. Sodium was used as the impurity metal because (1) it has a much lower work function than tungsten so that large changes in work function could be obtained; (2) it has the lowest atomic number of any metal suitable for such a purpose; (3) sodium has sufficiently high vapor pressure that it can be distilled to ensure its purity.

METHOD AND APPARATUS

Since the results of this work depend largely on the use of pure gas-free sodium, much care was taken in its preparation. Chemically pure sodium was twice distilled in a Pyrex still[6] under a residual gas pressure of less than 10^{-6} mm Hg. A sealed-off pellet of sodium was then placed in the side arm assembly of the main tube (see Fig. 1). This arrangement, based on experiments

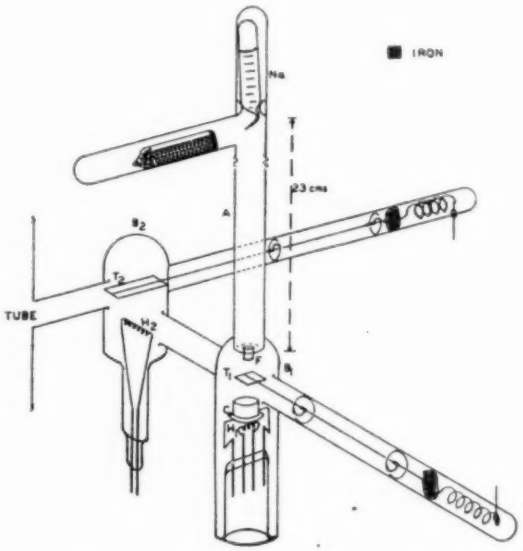

FIG. 1. Side arm assembly for the final distillation of sodium.

* Complete thesis on file at M.I.T. library.
† Now with the National Research Council, Ottawa.
[1] L. Treloar, Proc. Roy. Soc. **49**, 392 (1937).
[2] J. H. de Boer and H. Bruining, Physica **6**, 941 (1939).
[3] A. E. Hastings, Phys. Rev. **57**, 695 (1940).
[4] P. L. Copeland, Phys. Rev. **58**, 604 (1940).
[5] E. A. Coomes, Phys. Rev. **55**, 6 (1939).
[6] J. Strong, *Experimental Physics* (Prentice-Hall, Inc., 1938), p. 535.

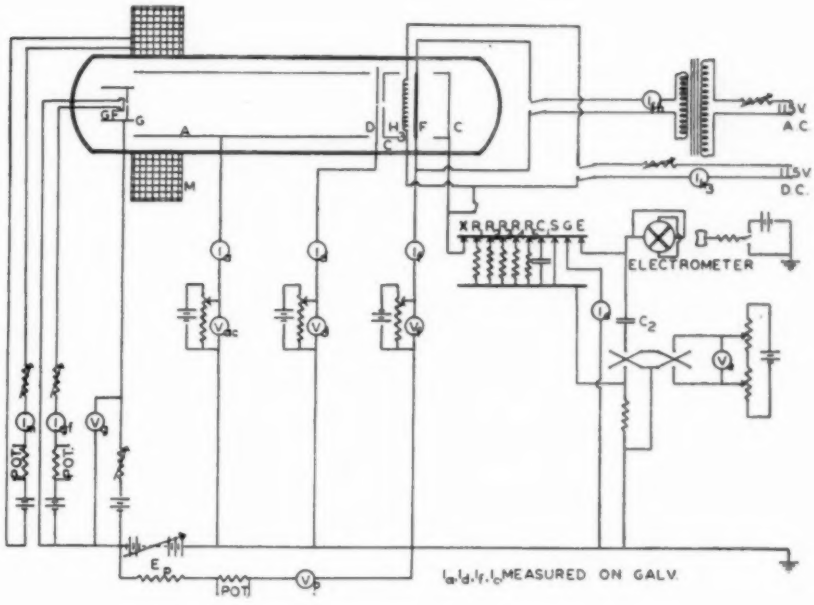

FIG. 2. Measuring circuit and schematic diagram of the essential members of the main tube.

by Cashman,[7] allowed the sodium to be redistilled in the final tube without contacting the glass envelope. After the pellet was broken, the sodium was warmed up until it ran down into crucible C. With transport T_1 out of the way, the outer layers of sodium, which might be gassy, were evaporated on to the walls of bulb B_1. This coating acted as a getter. The sodium in the crucible was then evaporated on to transport T_1 which was then moved into bulb B_2. Similarly the sodium was evaporated on to transport T_2 which could be moved into the main tube and the sodium evaporated off it on to the target. Preliminary experiments were made to test the efficacy of this treatment. The photoelectric current, arising from a beam of light focused on the target, was observed as sodium was deposited on it. This current rose to a maximum and then fell off as the thickness of the sodium layer was increased. The target was then heated so as to evaporate off the sodium. The current maximum obtained here agreed within about 7 percent with that previously obtained. A discussion of this test was given by Becker.[8]

The final tube was similar to those previously described[5,9] (see Fig. 2). A magnetically focused electron gun was used to obtain a better focused beam for low energy electrons than could be obtained with electrostatic focusing. This allowed fewer metal parts to be used in the gun assembly, resulting in greater ease of outgassing. Since oxide coated cathodes seldom can be outgassed properly, the gun filament was constructed from a flat tungsten ribbon. The potential drop across the emitting portion was comparable with the mean thermionic energy of the electrons after being emitted from the cathode. Beam currents of about 2 microamperes were obtained at a gun filament temperature of only 1600°K. This produced no measurable photoelectric current from the target even at optimum sodium coverage. Good beam focusing was obtained throughout the primary voltage range of 75 to 1500 volts, the spot size never exceeding 1 mm in diameter as observed visually on a willemite screen. Tests showed that the stray electron current 3 mm away from the center of the beam was less than 0.1 percent of the focused beam current.

On leaving the gun, the beam passed through a diaphragm, a hole in the cylindrical collector, and struck the target. These parts were carefully oriented so that the primary beam could not "see" the collector or a small heater filament placed inside the collector to evaporate sodium off transport T_2 on to the target.

The outgassing schedules and general vacuum

[7] R. J. Cashman and W. S. Huxford, Phys. Rev. **48**, 734 (1935).
[8] J. A. Becker, Trans. Faraday Soc. **28**, 155 (1932).
[9] H. Bruining and J. H. de Boer, Physica **5**, 17 (1938).

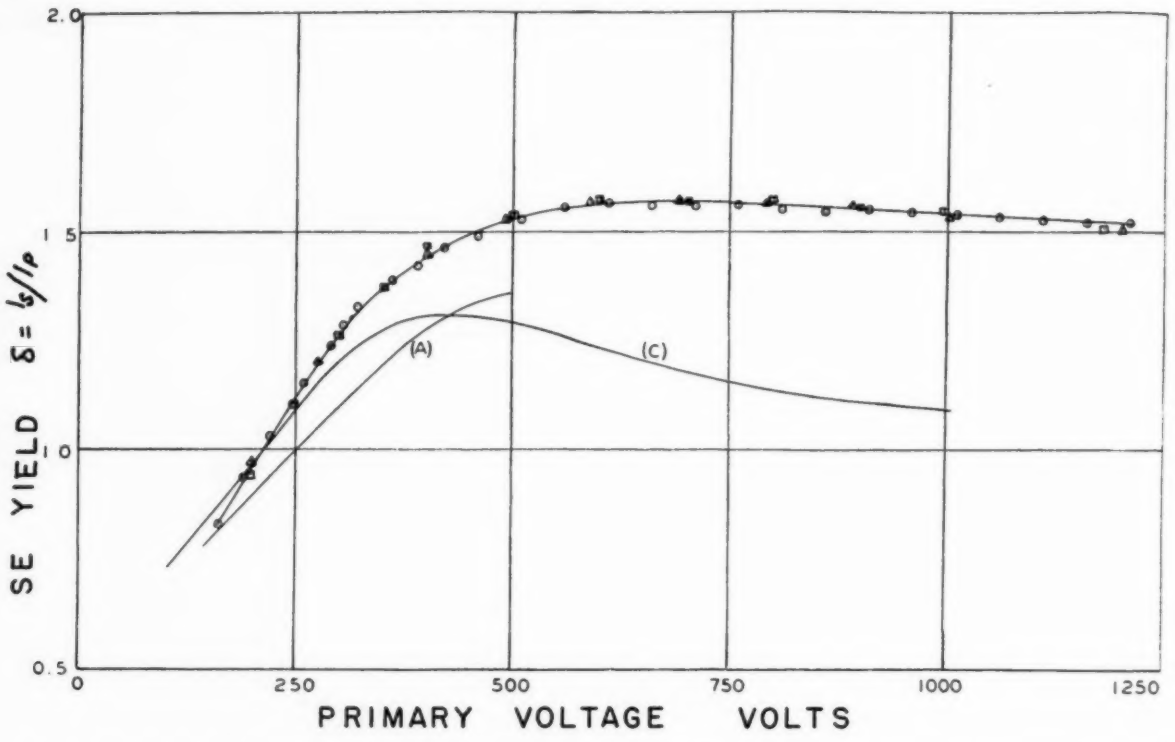

FIG. 3. Experimentally determined secondary emission characteristic of clean tungsten. Curve (*C*) Coomes; curve (*A*) Ahearn. ⊡, 260 hours aging of target; ⊙, 300 hours aging of target; △, equilibrium after re-evacuation of tube. Tube No. 7241.

technique employed have been previously described by Nottingham.[10] The only materials used in the tube were tungsten, pre-outgassed tantalum, sodium, iron, and Ba-Al getter pellets. Wherever iron was employed for its magnetic properties, it was enclosed in an evacuated glass envelope. Great care was taken to outgas the tungsten filaments, in particular the target filament. The latter was first flashed at 2700°K for one minute to ensure the production of a polycrystalline surface. Microphotographs of the surface showed that the average diameter of the crystalloids formed was about 2 microns. The outgassing schedule consisted of short flashes at 2700°K followed by prolonged heating at 1800°K. This was continued for 250 hours after which time no changes greater than the experimental error of 1 percent in thermionic emission at 1200°K, or in secondary emission at room temperature, from the target were observed. These tests formed very sensitive indicators of the vacuum conditions in the tube. These readings could be reproduced twenty-four hours later within 1 percent. It was estimated that the pressure in the tube was of the order of 10^{-8} mm Hg. All measurements were made with the tube sealed off and gettered.

The measuring circuit is shown in Fig. 2. The accelerating voltage E_p was obtained from a regulated power supply. Thermionic measurements on the target were made with a d.c. supply, the current through the filament being measured by a potentiometer. The current supplying the 500-watt projection lamp used as a source for photoelectric measurements was kept constant similarly.

CONTROL MEASUREMENTS AND RESULTS

It was most important that the effects due to stray electrons be determined completely or otherwise the results might have been quite misleading. Careful tube construction reduced these effects but could not entirely eliminate them. Hence an extensive investigation of the electrical characteristics of the tube was under-

[10] W. B. Nottingham, J. App. Phys. **8**, 762 (1937).

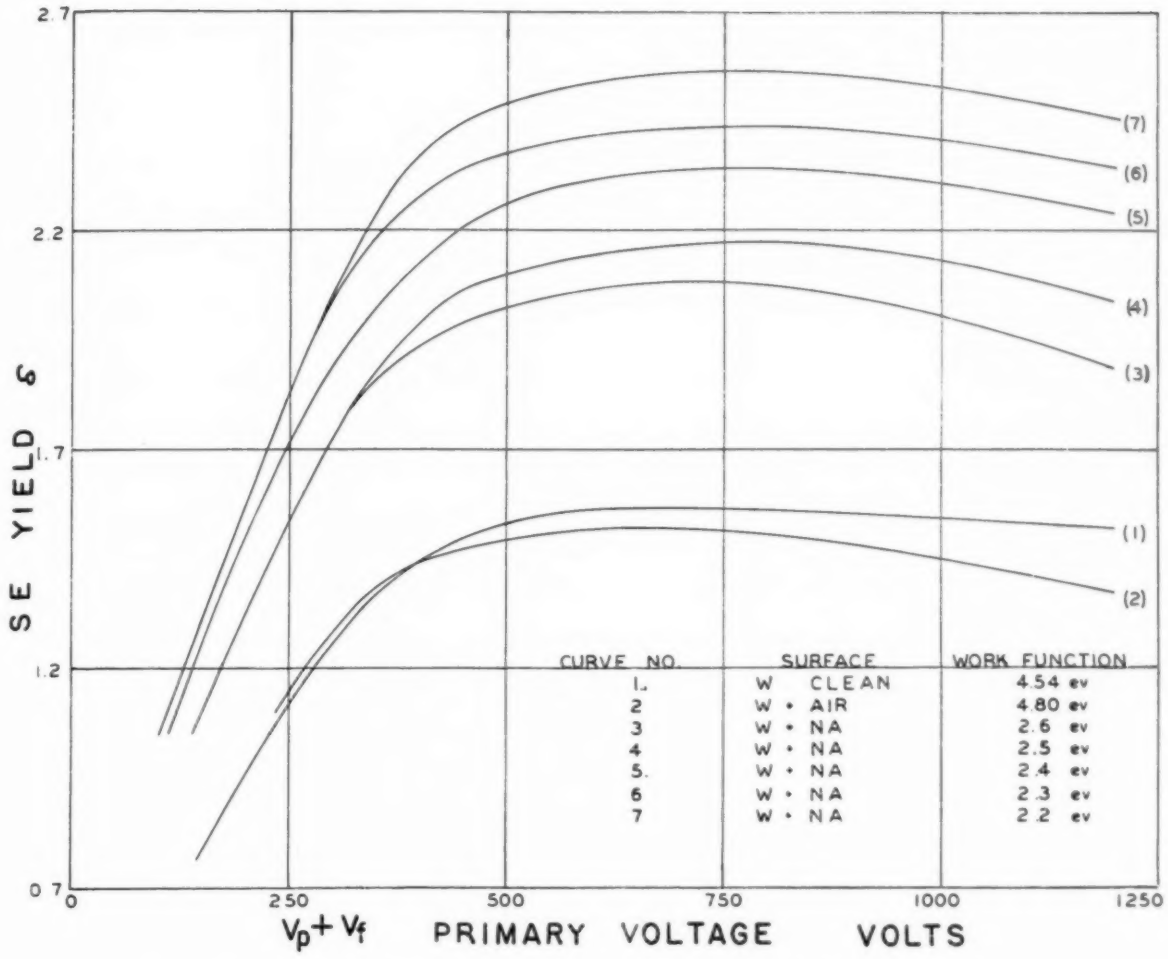

FIG. 4. Secondary emission characteristic of tungsten covered with thin films of sodium.

taken. Secondary emission yield curves were taken as a function of the potential of: (1) gun grid G, (2) gun anode A, (3) diaphragm D, (4) target F, (5) heater filament H_3, all with respect to the collector C. The effect of the position of the focusing magnet and slight defocusing of the beam was also studied. The final measurements of secondary emission were taken with the gun anode at +20 volts, the diaphragm at +10 volts, the filament at −20 volts, all with respect to the collector, and the heater filament connected to the collector. It appeared that these values were the best to reduce extraneous effects to a minimum. The above-mentioned set of measurements indicated that the absolute value of the results here presented for the secondary emission from clean tungsten was not in error by more than 6 percent. Individual measurements could be reproduced to within 1 percent.

Figure 3 shows the curve obtained for the secondary yield from clean tungsten as compared with previously published results. Figure 4 gives the curves obtained by the addition of an impurity to the surface. Curve 2 was obtained when air accidentally was liberated in the tube at a pressure of about 10^{-6} mm Hg. There was no sodium in the tube at that time. The increase in work function was measured thermionically. The tube was re-evacuated and, after again ageing the target, the results previously obtained for a clean tungsten target were reproduced within 1 percent. Curves 3–7 (Fig. 4) were obtained by depositing sodium on the filament as described above. The work function of the

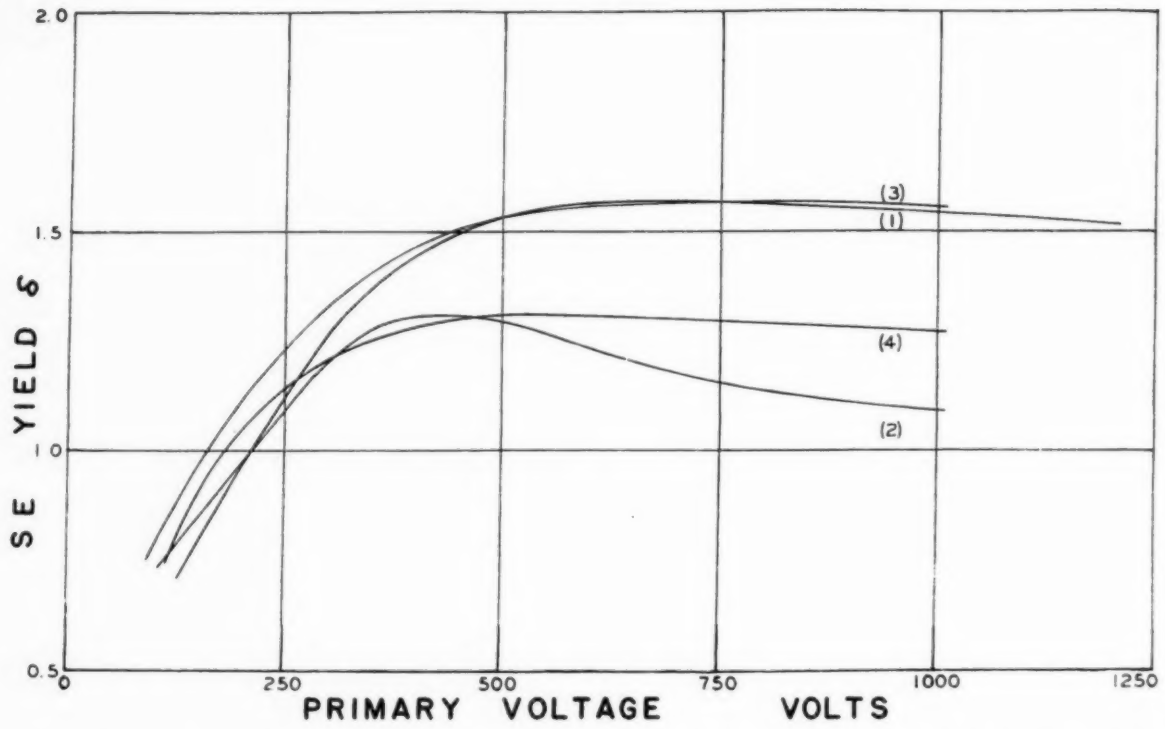

FIG. 5. Secondary emission characteristic of clean tungsten; comparison of theoretical and experimental curves. Curve 1, experimental—McKay; curve 2, experimental—Coomes; curve 3, theory—Wooldridge, $\delta_m = 1.355$; curve 4, theory—Wooldridge, $\delta_m = 1.109$.

surface was measured by obtaining the photoelectric long wave limit by the use of calibrated Wratten filters. All secondary emission measurements were made with less than a monomolecular film of sodium on the surface. This was ensured by first depositing considerable sodium on to the target. Sodium was then evaporated off until the photoelectric current passed through a maximum and had begun to decrease. Bosworth[11] has shown that the minimum work function for sodium on tungsten occurs at a surface coverage of 75 percent of that for a monomolecular film.

To determine whether or not the secondary yield from sodium on tungsten ever falls below that for clean tungsten, the target, coated with sodium, was maintained at an elevated temperature and the secondary yield was measured continuously as sodium was being evaporated off the target. This was done for various primary voltages but at no time did the secondary yield fall below the value for clean tungsten. It was also shown that the secondary yield from clean tungsten is independent of the temperature of the target up to 1000°K. This limit was set by the increase of thermionic emission.

[11] R. C. L. Bosworth, Proc. Roy. Soc. **A162**, 31 (1937).

DISCUSSION OF RESULTS

It is interesting to compare these experimental results for clean tungsten with those obtained by the application of Wooldridge's theory.[12] If we assume an atomic volume of 9.63 cm^3/g atom,[13] a work function of 4.54 ev,[14] and the height of the Fermi band of 8.0 ev,[15] the secondary yield as a function of primary energy can be calculated provided that the height of the theoretical curve is adjusted to equal the maximum height obtained experimentally. Figure 5 shows these curves fitted to Coomes' results[5] and to those here obtained. In the latter case, the agreement is reasonably good.

[12] D. E. Wooldridge, Phys. Rev. **56**, 562 (1939).
[13] Mott and Jones, *Properties of Metals and Alloys* (Oxford University Press, 1936).
[14] W. B. Nottingham, Phys. Rev. **49**, 78 (1936).
[15] Hughes and Dubridge, *Photoelectric Phenomena* (McGraw-Hill, 1932), p. 76.

The experimental results with clean tungsten differ considerably from Coomes' data. His yields were lower than any previously obtained. It is possible that his results could have been affected by the measurement of secondaries produced within the gun itself which would have the effect of apparently lowering the yield.

The results obtained for sodium on tungsten also disagree with Coomes' results which showed a lowering of the yield when the work function was reduced by the application of thorium on tungsten. However, they are in substantial agreement with work by Treloar,[1] deBoer and Bruining,[2] and others.[3,16] The careful distillation of the sodium, the outgassing procedure employed, and the reproducibility of the results appear to preclude the influence of oxygen on these results. Since the thickness of the sodium film was always less than a monomolecular layer, it is unlikely that absorption of electrons within the layer was appreciable. Thus we see that the secondary emission yield is not independent of the work function of the emitting surface but increases as the work function is decreased. This is in accord with Wooldridge's theory.[12]

I sincerely appreciate the many helpful suggestions given, and the continued interest shown, by Professor W. B. Nottingham, under whose direction this research was carried out. I am grateful to Dr. W. Painter of the RCA Manufacturing Company for his suggestions regarding electron gun design, to the electronics group at M.I.T. with whom many enlightening discussions were held, and to Mr. Lawrence W. Ryan who ably performed the difficult glass-working operations demanded in this research.

[16] K. Sixtus, Ann. d. Physik **3**, 1017 (1929).

JUNE 1 AND 15, 1942 PHYSICAL REVIEW VOLUME 61

Matter Waves and Electricity

CORNELIUS LANCZOS
Purdue University, Lafayette, Indiana

(Received March 18, 1942)

Classical four-dimensional relativity gives a most natural and harmonious interpretation of the three basic phenomena of nature: gravity, electricity, and the wave structure of matter, provided that the basic assumptions of the Einsteinian theory are modified in two respects: (1) the fundamental invariant of the action principle is chosen as a quadratic instead of a linear function of the curvature components; (2) the static equilibrium of the world is replaced by a dynamic equilibrium. Electricity comes out as a second-order resonance effect of the matter waves. The matter waves are gravitational waves but superposed not on an empty Euclidean space but on a space of high average curvature.

1. INTRODUCTION

THE belief in the fundamental unity of all nature is so deeply rooted that attempts to describe all natural phenomena from one unified basis occurred again and again throughout the history of physics. The great unification of geometry and physics by Einstein gave new impetus to such speculations. Various courses were open to generalize the original frame of relativity. The abandonment of the Riemannian line element in favor of a more general metrical structure by Weyl[1] and Eddington,[2] the introduction of "distance parallelism" by Einstein,[3] the change from a metrical to a projective platform by Veblen and Hoffmann,[4] the enlargement by a fifth dimension by Kaluza,[5] and the further development of that theory by Einstein and Bergmann[6] are some of the major landmarks in these efforts. The author's own attempt,[7] inaugurated about ten years ago, follows a somewhat different line. The frame of Riemannian geome-

[1] H. Weyl, Math. Zeits. **2**, 384 (1918).
[2] A. S. Eddington, Proc. Roy. Soc. **99**, 104 (1921).
[3] A. Einstein, Berl. Ber., pp. 217 and 224 (1928).
[4] O. Veblen and B. Hoffmann, Phys. Rev. **36**, 810 (1930).
[5] Th. Kaluza, Berl. Ber., p. 966 (1921); A. Einstein, Berl. Ber., p. 23 (1927).
[6] A. Einstein and P. Bergmann, Ann. of Math. **39**, 683 (1938).
[7] C. Lanczos, Phys. Rev. **39**, 716 (1932).

try is not sacrificed nor is the four-dimensional structure abandoned. The generalization consists in the choice of a new action principle which leads to field equations more general than the Einsteinian gravitational equations. The new field equations are of fourth order in the g_{ik}. However, applying the methods of Hamiltonian dynamics to the variation of the action principle, one can vary metrical tensor and matter tensor as independent variables and consider the resulting system of field equations as a coupled system of differential equations of second order for the twenty variables g_{ik} and R_{ik}.[8] These equations are analogous to the basic equations of elasticity and correspond to an elastic theory of the ether.

The author could show in his previous publication[7] that the generalized action principle is in perfect harmony with the equations of electricity. The integration of the field equations for infinitesimal fields gives rise to a free vectorial function ϕ_i which has all the properties of the vector potential. This vectorial function can be introduced as an undetermined Lagrangean multiplier, caused by the conservation laws of the matter tensor. The field equation for ϕ_i follows from the conservation laws and comes out as the nabla equation, in complete analogy to the field equation of the ordinary electromagnetic vector potential. The conservation law of the electric charge, expressed by the vanishing of the divergence of ϕ_i, can also be established. Finally, the dynamical interaction of charged particles can be deduced by an application of the action principle to the problem of motion. The resulting force is the electromotive force of Lorentz.

Hence, in spite of the fact that the deductions are based on the symmetric gradient

$$F'_{ik} = (\partial\phi_i/\partial x_k) + (\partial\phi_k/\partial x_i) \qquad (1.1)$$

rather than on the customary anti-symmetric gradient

$$F_{ik} = (\partial\phi_i/\partial x_k) - (\partial\phi_k/\partial x_i), \qquad (1.2)$$

the results are in agreement with the observable physical facts. The change of sign from plus to minus occurs in the ponderomotive force and that suffices to define the field strength according to (1.2) and deduce the Maxwellian equations.

While the theory is thus able to yield the basic theoretical aspects of electricity, it contains one fundamental difficulty which hampered all further progress up to recent times. As it was indicated in the closing chapter of the quoted paper,[9] the theory cannot explain the existence of free electric charges as long as static conditions prevail. Indeed, let us consider an electric field with the electrostatic potential ϕ_4. According to the theory the gradient of ϕ_4 represents the three components T_{i4} of the matter tensor and has to be interpreted as an energy flux. Such an energy flux must have a source. It requires the creation or destruction of matter which is in contradiction to the empirically well-established stability of the mass of electrically charged particles.

Recent researches concerning the dynamical problem of a particle[10] started the author on an entirely new track, furnishing him eventually with that new viewpoint which has to be added to the quadratic action principle before any further progress can be made. It is the *dynamical* viewpoint which replaces the essentially static considerations of the previous researches. The new departure reveals that the problem of electricity cannot be separated from the problem of matter waves since electricity is an accompanying second-order effect of the matter waves. The consistent pursuance of the dynamical viewpoint leads to such interesting results that a short non-technical draft of the new theory, without extended mathematical computations, seems to be justified.

2. THE QUADRATIC ACTION PRINCIPLE

If the Lagrangean function of the universal action principle shall be quadratic in the curvature components, there seems to be an abundance of five fundamental invariants. However, two of these invariants are inactive as far as variation goes while the remaining three invariants are reducible to but two on account of an algebraic identity which exists between them. These relations between the basic invariants were established by the author,[11] not knowing that they were deduced before by Weitzenboeck,[12] Bach,[13] and Juettner.[14]

[8] C. Lanczos, Zeits. f. Physik **96**, 76 (1935).

[9] Cf. reference 7, p. 735.

[10] C. Lanczos, Phys. Rev. **59**, 813 (1941).

[11] C. Lanczos, Ann. of Math. **39**, 842 (1938).

[12] R. Weitzenboeck, Wien. Ber. **129**, 683 (1920).

[13] R. Bach, Math. Zeits. **9**, 110 (1921).

[14] F. Juettner, Math. Ann. **87**, 270 (1922); cf. reference 17, footnote 1.

The two remaining invariants can be combined by an *a priori* undetermined numerical factor c and thus the Lagrangean function of the fundamental action integral becomes:

$$L = R_{\alpha\beta}R^{\alpha\beta} + cR^2. \tag{2.1}$$

The previous investigation left c an undetermined number since there seemed to be no logical reason why one particular value of c should be preferred. This distressing uncertainty can now be removed and the action principle of the world uniquely determined. There is actually one special value of c which is distinguished by particularly desirable properties.

We introduce a new tensor S_{ik} defined as follows

$$S_{ik} = R_{ik} - \tfrac{1}{4}\kappa R g_{ik} \tag{2.2}$$

with the undetermined numerical factor κ. The Lagrangean function (2.1) can now be united into the single expression

$$L = S_{\alpha\beta}S^{\alpha\beta}, \tag{2.3}$$

provided that the following condition holds:

$$\kappa(2-\kappa) + 4c = 0. \tag{2.4}$$

To any given $c \geqq -\frac{1}{4}$ a corresponding real κ can be found.

Since the action integral is quadratic in the S_{ik}, the solution

$$S_{ik} = 0 \tag{2.5}$$

is obviously a possible solution of the field equations. This solution is the most stable of all possible solutions since it minimizes the action integral to zero. It is reasonable to assume that this particularly stable solution of the field equations will correspond to the average metrical structure of the world on which the fields of the material particles are superposed as small perturbations. This metrical field is obviously of decisive importance for all phenomena of physics. Ordinarily we identify it with the Euclidean metrics but this would not serve our present purposes. It is desirable to have a specific name for the metrical background of the world as it exists if the central fields of the individual particles are stripped away; the name "metrical plateau" seems to be appropriate and will be adopted for the present paper. The metrical plateau contains the bulk of the geometry of nature; the fields of the individual particles are merely small perturbations of the basic plateau.

The condition (2.5) yields the following field equations:

$$R_{ik} - \tfrac{1}{4}\kappa R g_{ik} = 0. \tag{2.6}$$

Contraction gives

$$(1-\kappa)R = 0. \tag{2.7}$$

Now if κ is different from 1, we get at once

$$R = 0 \tag{2.8}$$

and (2.6) yields

$$R_{ik} = 0. \tag{2.9}$$

Since the field equations $R_{ik} = 0$, if singularities are excluded, do not go beyond the Euclidean metrics, the metrical plateau of the world would come out as the customary Euclidean space of special relativity. But then the theory would not contain anything that could possibly lead to a reasonable explanation of the atomistic structure of matter, in want of a universal constant of atomistic dimensions. Consider, however, the exceptional value

$$\kappa = 1. \tag{2.10}$$

The vanishing of R is now avoided. With this value of κ the constant c becomes

$$c = -\tfrac{1}{4}. \tag{2.11}$$

The definition of S_{ik} is now:

$$S_{ik} = R_{ik} - \tfrac{1}{4}R g_{ik}. \tag{2.12}$$

This S_{ik} was once suggested by Einstein[15] as a possible substitute for the matter tensor T_{ik}. It is an under-determined quantity, leaving the scalar curvature R arbitrary. The purpose of this under-determination was to provide gravitational forces which could counteract the electrostatic forces of an electron and thus keep the electron from exploding. However, this under-determination leads to unacceptable results.

The present theory does not lead to any under-determination, not even for the value (2.11) of the constant c. The field equations yield for the scalar R the exact equation

$$(1+3c)\Delta R = 0, \tag{2.13}$$

where Δ is the invariant four-dimensional Laplacean operator. The critical value of c which

[15] A. Einstein, Berl. Ber., p. 349 (1919).

leads to the loss of one equation is thus $-\frac{1}{3}$ and not $-\frac{1}{4}$. The choice (2.11) preserves the field Eq. (2.13), and we can put

$$R = \text{const.} = 4\lambda \tag{2.14}$$

as the only reasonable solution of that equation. The field Eqs. (2.6) now become:

$$R_{ik} = \lambda g_{ik}, \tag{2.15}$$

which are Einstein's cosmological equations. The constant λ is an arbitrary constant of integration. The λ term is of an entirely decisive importance because, as the following chapter will show, λ is a *microscopic* and not a macroscopic constant, establishing a universal gauge of atomic dimensions in the world.

In order to remove the degeneracy of the Eq. (2.12), we can put

$$\kappa = 1 - \epsilon \tag{2.16}$$

and consider ϵ as an exceedingly small number. We now have

$$S_{ik} = R_{ik} - \lambda g_{ik} + \epsilon\lambda g_{ik} \tag{2.17}$$

and the basic metrical plateau is no longer characterized by the equations $S_{ik} = 0$, but by the "cosmological equations"

$$S_{ik} = \epsilon\lambda g_{ik}, \tag{2.18}$$

where $\epsilon\lambda$ is of cosmological smallness.

3. FOURIER ANALYSIS OF THE RIPPLED METRICAL PLATEAU

We assume that the basic metrical plateau on which the fields of the individual particles are erected is not the smooth Euclidean space of four dimensions with which special relativity operates but a space rippled by a diffuse cosmic radiation which fills out the entire four-dimensional space-time manifold. Although we know that our space is probably of a closed spherical structure, we replace that sphere for the purpose of the mathematical analysis by a huge box of cubic shape. We assume that the g_{ik} of this world are nearly Euclidean so that we may put

$$g_{ik} = \delta_{ik} + \epsilon\gamma_{ik}, \tag{3.1}$$

where ϵ is an infinitesimal expansion parameter. The quantities γ_{ik} are of an oscillatory nature on account of the radiation which fills the space. We apply a Fourier analysis to the γ_{ik}, expanding them into an infinite Fourier series with a basic wave-length which is extremely large. The terms of the Fourier analysis have constant amplitudes. The Fourier analysis is of the following form:

$$\gamma_{ik} = \sum_{\substack{\nu_1 \cdots \nu_4 \\ -\infty}}^{+\infty} A_{ik}^{(\nu_1 \cdots \nu_4)} \times \exp\left[i(\nu_1 x + \nu_2 y + \nu_3 z + \nu_4 c t)\right]. \tag{3.2}$$

We now examine the expression of the Einsteinian curvature tensor R_{ik}. We notice that the terms of this tensor can be split into two parts. The part R'_{ik} is formed of partial derivatives, while the part R''_{ik} cannot be transformed into partial derivatives. Assuming that our reference system is normalized by the customary condition:

$$\partial g^{\frac{1}{2}} g^{i\alpha} / g^{\frac{1}{2}} \partial x_\alpha = 0, \tag{3.3}$$

we obtain the following expression for R''_{ik}, neglecting quantities of higher than second order which are irrelevant for our present purpose:

$$R_{ik}'' = -\frac{1}{4}\left(\frac{\partial\gamma_{\alpha\beta}}{\partial x_i}\frac{\partial\gamma_{\alpha\beta}}{\partial x_k} - \frac{1}{2}\frac{\partial\gamma}{\partial x_i}\frac{\partial\gamma}{\partial x_k}\right) - \frac{1}{2}\left(\frac{\partial\gamma_{i\beta}}{\partial x_\alpha}\frac{\partial\gamma_{k\beta}}{\partial x_\alpha} - \frac{1}{2}\frac{\partial\gamma_{ik}}{\partial x_\alpha}\frac{\partial\gamma}{\partial x_\alpha}\right). \tag{3.4}$$

These terms give rise to a phenomenon that Schroedinger called "resonance catastrophe." The terms of R'_{ik} are obtained by differentiation and thus can give nothing but strictly periodic contributions; a constant term could arise only if the function to be differentiated were a linear function of t or the other coordinates which contradicts the boundary conditions in infinity. The terms of R''_{ik}, however, lead to constant terms, in addition to the periodic terms. Each frequency of the Fourier spectrum (3.2) is in resonance with itself and produces a constant term. Although these constants are individually small, yet in view of the extended nature of the Fourier spectrum and the very high frequency of the peak of the radiation (the realm of cosmic-ray frequency) these constants sum up to excessively high values, in spite of the smallness of ϵ.

These constants in the Fourier sum of R_{ik} cannot be compensated. They remain as unsaturated terms and the "resonance catastrophe" would occur if the metrical plateau had to satisfy the field equations $R_{ik} = 0$. We have to abandon these

field equations in favor of a more general possibility which avoids the difficulty of resonance terms.

Since each component of the tensor R_{ik} yields a constant as the average value of that component, a constant tensor ρ_{ik} is generated, characterizing the average curvature of the basic metrical plateau. The principal axes of this tensor designate a distinguished reference system of the space-time manifold. If, however, the cosmic radiation is evenly distributed over all directions of the four-dimensional world, then the tensor ellipsoid of that constant tensor degenerates into a sphere and the principal axes become undetermined. In that case the tensor ρ_{ik} must get the form:

$$\rho_{ik}=\lambda\delta_{ik}. \tag{3.5}$$

This, however, is exactly the condition that the constant tensor ρ_{ik} has to fulfill if the field equations $R_{ik}=0$ are modified to the "cosmological equations"

$$R_{ik}=\lambda g_{ik}. \tag{3.6}$$

We thus return to our Eq. (2.15) obtained before by integrating the field equations.

In view of the dynamical equilibrium of the world the cosmological Eqs. (3.6) obtain an entirely new significance. Originally these equations were introduced by Einstein in order to describe the cosmological behavior of the world at large. The λ term is an excessively small correction term since λ is inversely proportional to the square of the average curvature radius of the world. The cosmological term can have no influence on the microscopic structure of matter. Its function is merely to regulate the metrical behavior of the world in astronomical dimensions. In the present theory the λ term is *excessively large*. The constant λ is inversely proportional to the square of a length of nuclear dimensions. We get the apparently paradoxical result that *a statistically Euclidean rippled world whose metric is nearly constant, may nevertheless generate an exceedingly strong average curvature*. The change from statical to dynamical relativity spans the tremendous gap between atomistic and cosmic dimensions. In the static consideration a high average curvature would either mean that the world shrinks to nuclear dimensions, or that the curvature radius of the world explodes with a terrific speed. The tremendous pressure created by the cosmological term must lead to an explosion of the world. In the dynamical consideration that tremendous pressure is evenly distributed over a great many vibrations, each one carrying a very small amount of the burden. The situation is comparable to the problem of the electron which should explode under the influence of the tremendous electrostatic repulsive forces. Here, too, if the force is considered as a dynamic and not a static phenomenon, the difficulty is at once removed, as the next paragraph will show.

It is obvious that the rippled structure of the metrical plateau must lead to observable physical phenomena. Dynamically these fields will not show up easily. They produce extremely high vibrations with extremely small amplitudes which cannot be observed directly, except if occasional phase relations produce a case of temporary resonance. And thus, the wavy, eternally oscillating metrical plateau must create statistical effects. It is responsible for the general "uncertainty" and practical unpredictability of motion phenomena. Heisenberg's uncertainty principle may become realistically interpretable in terms of the perpetual statistically distributed ripples of the metrical plateau which incessantly travel in every direction. Moreover, these vibrations are responsible for the metrical structure of the material particles. These particles are not the static solutions of an eigenvalue problem, growing out from a smooth background as small hills on a generally flat surface. The material particles are themselves formed of vibrations which are in dynamical equilibrium with the cosmic waves of the basic metrical plateau. The strange and apparently classically unexplainable wave mechanical phenomena are interaction effects between the metrical waves which emanate from the individual particles. The following mechanical analogy may illustrate the situation. If a car travels on a gravelled road, it cannot keep to a straight line exactly. It reaches its destination only because the dimensions of the car are large compared with the size of the gravel. If the size of the car shrinks to dimensions which are comparable to the dimensions of the gravel, the car will reach its destination with large statistical fluctuations. If, in addition to that, the wheels of

a car were notched into a wavy profile and the rhythm of this wave were in resonance with the ripples on the road on which the car travels, the statistics which control the motion of this car would be necessarily of the nature of interference effects of products of wave functions, as it is the case in wave mechanical considerations. This crude picture is far from giving any explanation. Its purpose is not more than to show that the wave mechanical effects are not so puzzling any more if the metrical structure of the basic plateau on which the particles move has a dynamic instead of static character.

4. ELECTRICITY AS A RESONANCE EFFECT OF MATTER WAVES

We consider our action integral

$$A = \int S_{\alpha\beta} S^{\alpha\beta} d\tau, \tag{4.1}$$

where $d\tau$ is the four-dimensional volume element. The principle of least action requires that the variation of this integral shall vanish for arbitrary variations of the g_{ik}. We are not interested at present in the exact derivation of the field equations. We want to investigate the infinitely weak fields only. For that purpose we temporarily separate the variation of the g_{ik} and the variation of the S_{ik}. We know that the variation of the S_{ik} is reducible to the variation of the g_{ik}, by differentiation. But it is equally true that the variation of the g_{ik} is reducible to the variation of the S_{ik}, by integration. Hence it is permissible to consider the variation of the S_{ik} as the independent and the variation of the g_{ik} as the dependent variables. But the terms which contain the δg_{ik} are of second order and are thus negligible for our present problem.

The variation of the S_{ik} is not a free variation because the tensor S_{ik}, defined by (2.17), is subject to the conservation law of momentum and energy. This law takes the form:

$$\frac{\partial g^{\frac{1}{2}} S^{i\alpha}}{\partial x_\alpha} = -g^{\frac{1}{2}} \Gamma_{\alpha\beta}{}^{i} S^{\alpha\beta}. \tag{4.2}$$

If we consider this equation as an auxiliary condition of the variation, the application of the Lagrangean multiplier method gives a vectorial function ϕ_i as Lagrangean multiplier and we obtain for infinitesimal S_{ik} the field equation:

$$S_{ik} = (\partial\phi_i/\partial x_k) + (\partial\phi_k/\partial x_i) - 2\Gamma_{ik}{}^{\alpha}\phi_\alpha. \tag{4.3}$$

This field equation is not restricted to infinitesimal *metrical* fields g_{ik}. Its only restriction is that the *matter tensor* S_{ik} shall be infinitesimal. It cannot be used in the central nuclear region of a particle but it gives the field of a particle in the peripherical regions where the tensor S_{ik} is sufficiently small.

To show that the vectorial function ϕ_i has actually the properties of the ordinary vector potential, we at first notice that the definition (2.12) of the tensor S_{ik} requires the vanishing of the scalar S which gives:

$$\frac{\partial g^{\frac{1}{2}} \phi^{\alpha}}{\partial x_\alpha} = 0. \tag{4.4}$$

This equation expresses the conservation law of the electric charge.

The conditioning differential equation for ϕ_i follows if the solution (4.3) is put back into the divergence Eq. (4.2). We obtain with sufficient accuracy:

$$\frac{\partial^2 \phi_i}{\partial x_\alpha{}^2} = -\Gamma_{\alpha\beta}{}^{i} S^{\alpha\beta}. \tag{4.5}$$

This is the classical determining equation of the vector potential if the right side is interpreted as the four-dimensional "current vector."

We notice that ϕ_i comes out as an infinitesimal quantity of *second* order because both factors of the right side are infinitesimal.

It is shown in analysis that a potential function cannot be determined uniquely if the conditioning differential equation is not known everywhere. The differential Eq. (4.5) does not hold in the central region of the particle and thus the Eq. (4.5), although it gives the right mathematical law for ϕ_i, does not suffice to determine it. Fortunately, this uncertainty afflicts only the possible dipoles and multipoles of ϕ_i. *The "charge"-part of the potential*, which decreases with $1/r$ and which is the dominating and physically decisive term, *can be uniquely determined, in spite of the uncertainty of the central region.*

In order to understand the true significance of the vector potential and its main mathematical properties, let us examine the nature of the

conservation law (4.2) more closely. We encounter here once more a "resonance catastrophe" of a definite type. This time the difficulty does not arise from the fact that the left side of the equation is a sum of derivatives while the right side is not. As it was shown by Einstein,[16] the right side of the equation can be transformed into a sum of derivatives. However, let us apply the Gaussian integral transformation to both sides of the divergence equation. The surface integral obtained on the left side vanishes if S_{ik} is zero everywhere on the boundary. The right side, however, does not vanish, even if S_{ik} is zero everywhere outside the particle. This shows that the field equation

$$S_{ik}=0 \tag{4.6}$$

for infinitesimal fields cannot be established without imposing a definite vectorial condition on the central part of the field. The physical interpretation of this situation is that although the matter tensor vanishes outside the particle, the momentum and energy *flux* through a closed surface surrounding the particle need not vanish. But then that flux has to be maintained and that is only possible if matter destroys itself or is created incessantly. We have here a similar resonance phenomenon as in the case of the plateau vibrations. Just as there a safety valve was provided by the cosmological term λg_{ik}, so in the new situation a similar safety valve is provided by the Lagrangean multiplier ϕ_i. This shows that the vector potential ϕ_i plays the same role for the matter waves that the cosmological constant λ plays for the plateau waves. In both cases a resonance catastrophe has to be avoided. Since the resonance is a second-order effect, we understand why electricity appears as a second-order surplus effect of the matter waves. *The flux of the electrostatic field balances the gravitational flux of the matter waves.* If this "pre-established harmony" between matter waves and electricity seems rather astonishing, one can explain it as a logical consequence of the nature of the vector potential as a Lagrangean multiplier. It is the avowed *purpose* of this multiplier to make the auxiliary condition of the matter tensor—and that is the conservation law of momentum and energy—possible and thus it is only natural that it is the function of the electric charge to provide an energy flux which compensates the permanent irradiation of the matter waves.

Of particular interest is the electrostatic charge e which enters in the "scalar potential" ϕ_4. We obtain:

$$-4\pi e=\int\frac{\partial\phi_4}{\partial x_\alpha}\nu^\alpha d\sigma=\int S_{4\alpha}\nu^\alpha d\sigma=\frac{1}{2}\int\frac{\partial g_{\alpha\beta}}{\partial x_4}S^{\alpha\beta}dv, \tag{4.7}$$

where dv is the three dimensional volume element. This volume integral can be transformed into a surface integral according to the fundamental theorem of Einstein[16] that the gravitational momentum and energy flux can be rigorously transformed into a surface integral. This shows that the electric charge can be computed by making use of a closed surface surrounding the particle *at any arbitrary distance* so that the behavior of the unknown central field does not influence the electric charge.

The expression (4.7) shows directly that it is the oscillation of the metrical tensor g_{ik} which generates the electric charge. We notice, too, that a change of the sign of the time axis changes the charge from plus to minus, without changing its absolute value. Such a change in the direction of $x_4=ict$ means for the matter waves that *outgoing waves are changed into incoming waves.* The duplicity of positively and negatively charged particles finds thus its explanation by the fact that there is an equal chance for outgoing as for incoming waves. Notice that this possibility is in no contradiction to the phenomena of the retarded potential which are always based on outgoing and not on incoming waves. The matter waves are eternal oscillations which have no beginning and no end and thus "outgoing" and "incoming" refers merely to a phase relation and not to something which comes in collision with our regular experiences as to the sequence of time events.

One of the main riddles of electricity is the peculiar unsymmetry of the masses of electron and proton. Can the present theory give a satisfactory solution of this puzzle? The calculations are not advanced yet to the point where this question can be answered. However, we have good reason to believe that the results will come

[16] A. Einstein, Ann. d. Physik **49**, 769 (1916); cf. Eq. (50), p. 806; for the contravariant components, cf. reference 10, p. 817.

out satisfactorily. In the first place, the charge is a second-order effect, and so is the mass.[17] It seems possible that the charge shall have a linear influence on the mass. But apart from this, the present theory differs in one characteristic point from all previous attempts to apply relativity to the physical universe. We have called the tensor S_{ik} the "matter tensor" and we have interpreted the field equations

$$S_{ik}=0 \tag{4.8}$$

as "matter waves." These matter waves are gravitational waves but not of the ordinary type. If we consider the definition of the tensor S_{ik} and take in account that the field of a material particle is superposed on the cosmological Eqs. (2.15), we notice that the S_{ik} tensor of a material particle has to be defined as the *variation* of the quantity (2.17), taken for an infinitesimal change δg_{ik} of the metrical tensor g_{ik}:

$$S_{ik}=\delta R_{ik}-\lambda\delta g_{ik}. \tag{4.9}$$

This is not the ordinary curvature tensor with which we operate when the Einsteinian field equations are applied to infinitesimal fields. The curvature tensor (4.9) is superposed on a field of high average curvature and not on a field of zero curvature. The difference amounts to the same as the difference between Dirac's equation of the electron "with the mass term" and "without the mass term." If the mass term is omitted, the field quantities satisfy the ordinary wave equation and the waves propagate with light velocity. If the mass term is present, the wave equation is enlarged by a fifth term and the phase velocity of the matter waves is no longer the light velocity. Similarly, the ordinary gravitational waves of the Einsteinian theory, superposed on a Euclidean space, propagate with light velocity. The new matter waves, however, characterized by the vanishing of the tensor (4.9), propagate with an entirely different phase velocity. The introduction of a highly curved metrical plateau as the basic geometrical platform of the physical world removes the degeneracy of the Euclidean space and opens entirely new perspectives. The connection of the Eqs. (4.8) and (4.9) with the Dirac and possibly Schroedinger equations will be the subject of an independent investigation.

[17] C. Lanczos, Phys. Rev. **59**, 708 (1941).

5. CONCLUSIONS

The general viewpoints of a new theory have been developed which attempts to explain the basic physical phenomena of the world in a most harmonious and organic fashion. Although the fundamental action principle is chosen on strictly logical grounds, without augmenting it by phenomenological elements, yet the basic phenomena of electricity, matter waves, and gravity are derivable from it as necessary mathematical consequences. In addition to the quadratic action principle, an essentially new element enters the theory: the dynamical aspect. The metrical background of the world is not smooth but rippled by an extended spectrum of permanent vibrations. These vibrations, although observable only by their statistical effects and giving the source of the general uncertainty principle which prevails in nature, create a strong average curvature upon which the fields of the individual particles are erected. The matter waves associated with the particles are metrical waves which differ from the ordinary gravitational waves by the fact that they are metrical deformations of a strongly curved world and not of a flat world. This explains the abnormal phase velocity of these waves which differs widely from light velocity. Electricity is an accompanying resonance effect of the matter waves, necessary to maintain the undamped matter waves without energy losses. Although electricity is a second-order effect, yet for our world of observations it is by far more decisive than all other effects because it is *static* (in a proper reference system) while the waves of the basic metrical platform and also the matter waves of particles represent eternal oscillations of very high frequencies.

The theory presented here is far from being complete. It is not more than the first step toward a new land. But the author who has grappled with these ideas for ten years, groping in the dark and unable to solve the puzzle of the electric charge, until suddenly the dynamical aspect arrived, illuminating the entire scenery and melting away all difficulties—cannot doubt that here are the outlines of a theory which will be destined to bring the three basic phenomena of nature: gravity, electricity, and the wave theory of matter, into one inseparable unity.

Letters to the Editor

PROMPT publication of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is the third of the month. Because of the late closing date for the section no proof can be shown to authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not in general exceed 600 words in length.

The Theory of Absolute Reaction Rates and the Conductivity of Hydrocarbons at High Field Strengths

NORMAN DAVIDSON
500 Riverside Drive, New York, New York
April 28, 1942

IN a recent communication,[1] H. J. Plumley suggests that the currents observed when large electric fields are applied to liquid normal heptane are due to the ionization of the heptane molecules according to the equation:

$$C_7H_{16} \rightarrow C_7H_{15}^- + H^+ \text{ (solvated)}. \quad (1)$$

Every ion so created reaches the oppositely charged electrode without recombination or multiplication by collision. The slow step in the process is the ionization; in the presence of a field, favorably oriented molecules are more readily dissociated; on the basis of these assumptions, Plumley calculated the dependence of current on voltage and obtained fair agreement.

On the basis of these same assumptions and the theory of the absolute rate of reactions, it is possible to relate the energy of activation for reaction (1) to the observed current. The relevant equation is[2]

$$m = kT/h \exp(-\Delta H/RT) \exp(\Delta S/R),$$

where ΔH and ΔS are the heat and entropy of activation for the reaction (1). The rate constant m is calculated from the extrapolated value of the current at zero field strength, which from Plumley's data is about 10^{-13} amp./cm²/cm at 20°C, and the density of normal heptane. The entropy of activation may be neglected. (The necessity for favorable orientation with respect to the field is counterbalanced by the large number of hydrogen atoms available for dissociation. The activated complex would have a greater rotational entropy than the normal molecule, but this could not affect the rate by more than a factor of 10^4 and hence would affect the calculated value of ΔH by less than 5 kcal. The calculated value of ΔH is 38 kcal./mole; this represents the heat of activation for reaction (1) at zero field strength and hence is identical with the heat of ionization of liquid heptane. (The influence of a field of 5×10^5 volts/cm on the heat of activation is 8.4 kcal./mole at 20°C.)

This result tends to discredit the theory that the conductivity of heptane is due to the field facilitated ionization of heptane molecules. A reasonable estimate of the heat absorbed in the reaction $CH_4 \rightarrow CH_3^- + H^+$ in aqueous solution is 70 kcal.[3] Since the heat of hydration of gaseous protons is about 250 kcal./mole, the heat of solvation in a solvent of dielectric constant 1.9 (heptane) is about 120 kcal.; therefore the heat of ionization of a hydrocarbon in heptane solution is of the order of magnitude of 200 kcal./mole, rather than 38 kcal., as demanded by the theory under discussion.

A further discrepancy is noted if one considers the observed change in conductivity with temperature; from 20° to −80°, the current decreases by a factor of $10^{-2.5}$ (at 5×10^5 volts/cm, where the effect of ionic recombination is apparently negligible at −80°) whereas the calculated ratio on the basis of an activation energy of 38 kcal. is 10^{-10}.

Plumley briefly considers the possibility that the current is due to the ionization of an impurity dissolved in the heptane. It is perhaps worth pointing out that even for such a relatively easily ionizable substance as HCl, the heat absorbed in ionization in a hydrobarbon solvent is probably 120 kcal. or greater.

I am indebted to Dr. Plumley for helpful private correspondence and to Dr. F. H. Westheimer of the University of Chicago, who pointed out to me the applicability of the theory of absolute reaction rates to this problem.

[1] H. S. Plumley, Phys. Rev. **59**, 200 (1941).
[2] Glasstone, Laidler, and Eyring, *The Theory of Rate Processes* (McGraw-Hill, New York, 1941), p. 196.
[3] Baughan, Evans, and Polanyi, Trans. Faraday Soc. **37**, 377 (1941).

Ultimate Resolving Power of the Electron Miscroscope

L. I. SCHIFF
Randal Morgan Laboratory of Physics, University of Pennsylvania, Philadelphia, Pennsylvania
April 24, 1942

THE recent attainment of resolving powers approaching 30A with the transmission type electron microscope[1] raises the question of the theoretical possibility of obtaining images of the arrangement of atoms within a molecule. We shall assume in this discussion that a suitable object mounting and electron lenses of sufficiently high quality will ultimately be constructed, and consider only possible limitations on resolution due to diffraction and contrast.

Calculation of the scattering of fast electrons by atoms[2] shows that the angular divergence θ of the beam scattered elastically by a neutral atom of nuclear charge Ze is of order $e^2Z^{\frac{1}{3}}/\hbar v\gamma$, where v is the velocity of the electron and $\gamma=(1-v^2/c^2)^{-\frac{1}{2}}$; the angular divergence of the inelastically scattered beam is usually somewhat smaller. Since this determines the maximum effective aperture of the objective lens, the best resolving power is roughly $0.6\lambda/\theta=1.2\pi\hbar/mv\gamma\theta\approx4\hbar^2/me^2Z^{\frac{1}{3}}$. Adding to this the effective atomic radius for strong scattering given by the Thomas-Fermi model: $\hbar^2/me^2Z^{\frac{1}{3}}$, one obtains a result that is independent of v and is of the order of $\frac{1}{2}$ to 2A for most atoms.

A more serious restriction results from the requirement

that the image possess sufficient contrast to register on a photographic plate. For comparable intensities of elastic and inelastic scattering, the former will produce a stronger image than the latter, since it is coherent with the incident beam and can interfere with it. If we assume unit magnification and unit incident intensity, the integrated intensity is found to be simply the elastic scattering cross section σ_e; with an image radius a, the contrast is approximately twice the forward scattered amplitude, or $\approx 2(\sigma_e/\pi a^2)^{\frac{1}{2}}$. Making use of $^2\sigma_e \approx 22Z^{4/3}(h/mv)^2$ and $a \approx 5h^2/me^2Z^{\frac{1}{3}}$, one finds the contrast becomes $\approx 0.008Zc/v$. Since this must be at least 10 percent, the minimum atomic number for 60-kev electrons is $Z \approx 7$; this is somewhat smaller than the estimate recently obtained by Hillier[3] from a classical calculation.

The contrast limitation disappears if dark-field illumination is used. This can be obtained, for example, by forming an image of the electron source on the object, placing an annular aperture in the condenser lens, and adjusting the objective aperture so that the unscattered transmitted beam just fails to pass through it.[4] It would seem that in this case there is no simple limitation on resolving power. For suppose, as appears to be possible, that the electron source can be designed so that an electron from any part of the emitting surface could reach any part of the condenser aperture, thus making the whole condenser beam coherent. With an object in place, the objective aperture would then be illuminated about its edge by a coherently scattered beam, and this would give even greater resolution than could be obtained if the whole objective aperture were illuminated. Moreover, the problems involved in overcoming aberrations in the objective and condenser lenses would be greatly simplified if only the edges of these lenses were used.

The writer acknowledges with thanks several informative conversations on the construction and operation of the electron microscope with Drs. J. Hillier, E. G. Ramberg, and T. F. Anderson of the RCA Research Laboratory.

[1] V. K. Zworykin, J. Hillier, and A. W. Vance, J. App. Phys. **12**, 738 (1941).
[2] L. Marton and L. I. Schiff, J. App. Phys. **12**, 759 (1941).
[3] J. Hillier, Phys. Rev. **60**, 743 (1941).
[4] M. von Ardenne, *Elektronen-Übermikroskopie* (Springer, 1940), p. 37.

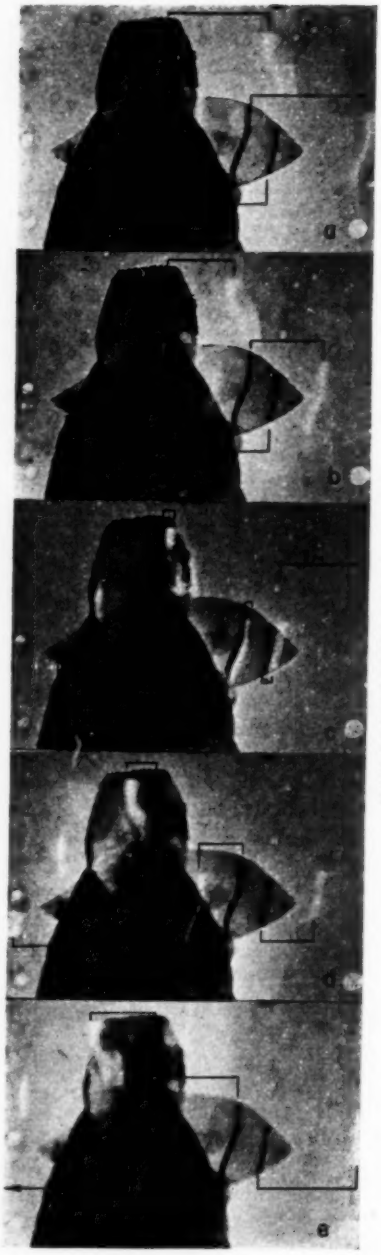

FIG. 1. A "through the focus" sequence of electron micrographs of $Al_2O_3 \cdot H_2O$ crystals demonstrating the reflection of electrons from properly orientated crystalline material. The bright regions representing the intersection of the reflected beam with the imaged plane and the corresponding anomalous darkening of those areas of the crystals in which the reflections occurred are indicated by the inked-in brackets.

The Observation of Crystalline Reflections in Electron Microscope Images

JAMES HILLIER AND RICHARD F. BAKER
RCA Manufacturing Company, Inc., Camden, New Jersey
April 14, 1942

BORRIES and Ruska[1] have shown that in the case of crystalline material the density of the electron-microscope image is not uniquely determined by the mass thickness of the specimen but is also dependent on the orientation of the crystals relative to the direction of the illuminating electron beam. This phenomenon was clearly demonstrated in micrographs of small single crystals of chromium smoke which could be made to appear either transparent or opaque by proper adjustment of the angle of incidence of the illuminating electron beam. Von Ardenne[2] extended the observations of this phenomenon to crystalline lamina which exhibited slight irregularities. In the latter case the electron image of the crystal contained dark bands, the position of which varied with the direction of the electron illumination. Von Ardenne stated that the dark bands could not be interpreted on the basis of mass-thickness variations in the crystalline lamina.

Similar observations have been made in this laboratory on a variety of materials with the result that the phenomenon has been shown to be due to Bragg reflections from those crystalline planes which are properly orientated.

In the above-mentioned published work small limiting apertures were used in the objective (angular aperture of the order of 3×10^{-3} radian) and these prevented the reflected electrons from reaching the image. In the present work comparatively large limiting apertures have been used which has made possible the demonstration of the existence of a strongly reflected electron beam. Figure 1 is a sequence of electron micrographs of $Al_2O_3\cdot H_2O$. The electron beam which illuminated the specimen had an angular aperture of 10^{-4} radian and an energy of 78 kilovolts. The maximum angular aperture of the objective system was 0.6 radian. The individual micrographs, *a* to *e*, of the sequence in Fig. 1 were obtained with the objective current set at values about that required for the best focus and are thus reproductions of the electron distribution, passing through those planes of the object space conjugate to the plane of the viewing screen. The micrographs are arranged *a* to *e* in order of increasing objective current, i.e., they correspond to planes of the object space situated successively closer to the objective lens.

In those regions of the crystal lamina where the crystal planes have the proper orientation the electron beam appears to be almost totally reflected. The dark and bright regions caused by this reflection are quite evident in the micrographs. Corresponding pairs can be identified by their similarity in shape and size. The dark region in the crystal and the corresponding bright region represent the position of the intersection of the image-forming and reflected rays, respectively, with the plane imaged. Thus, the change in separation of the corresponding dark and bright regions in the successive images is a measure of the angle through which the incident beam is reflected. It should be pointed out that the lens aberrations prevent the bright regions, due to the reflected rays, from coinciding with the corresponding dark areas when the instrument is in best focus.

As a final check on the nature of the phenomenon the following experiment was carried out. A large crystal, which, viewed at the high magnification of the final image screen, gave a strong reflection, was identified on the intermediate image screen and the bright spot due to the same reflection observed. The objective lens current was then slowly reduced to zero. As this was done the bright spot was seen to move out from the crystal and the axis of the lens system until in the limit it took up a position on one ring of the diffraction pattern of the material. In the limit (objective lens current zero) the arrangement of the apparatus is the same as a diffraction camera (a small area of the specimen illuminated by a narrow pencil of electrons) so that a diffraction pattern of the specimen is visible and the final position of the bright spot can be identified.

The authors wish to thank Dr. V. K. Zworykin for his many suggestions.

[1] B. von Borries and E. Ruska, Naturwiss. **28**, 366–367 (1940).
[2] M. von Ardenne, Zeits. f. Physik **116**, 736–738 (1940).

Proceedings of the American Physical Society

Minutes of the Meeting of the New England Section held at Worcester, Massachusetts, March 28, 1942

THE second meeting of the New England Section for the season 1941–42 was held at the Worcester Polytechnic Institute, Worcester, Massachusetts on March 28, 1942. Invited and contributed papers were given as listed below; abstracts of the contributed papers are appended.

Invited Papers

Edith H. Quimby, *Memorial Hospital, New York City:* **Physical Methods of Dosage Determination in X-Ray Therapy.** (30 minutes)

Joseph C. Boyce, *Massachusetts Institute of Technology:* **The Opportunities for the College Physics Department in the Present War.** (30 minutes)

Morton Masius, *Worcester Polytechnic Institute:* **Physics at Worcester Polytechnic Institute.**

Robert F. Field, *General Radio Company:* **The Polarization Parameters of Several Solid Dielectrics and Their Changes with Temperature and Composition.** (For abstract, see Abstract 32, page 737.)

Symposium on the Science Teachers' Training Program

Albert A. Bennett, *Brown University:* **The Relation of Mathematics Training to Physics Training.** (30 minutes)

Karl Lark-Horovitz, *Purdue University:* **Every New Science Teacher a Prospective Defense Training Teacher.** (45 minutes)

Abstracts of Contributed Papers

1. Ozone and Ultraviolet Light. Arthur W. Ewell,* *Worcester Polytechnic Institute.*—Rise in temperature increases the output of both ozone producing and ozone destroying radiation and increases the spontaneous deozonization—the net result being a decrease of about 50 percent in the ozone concentration for a rise in temperature from 7°C to 32°C. The ozone concentration produced by an ultraviolet high transmission lamp decreases with the relative humidity rather than the absolute humidity. For an increase from about 0 to 100 percent R. H., the ozone concentration decreases to one-fifth irrespective of the temperature in the range 7°C to 32°C. From whatever source, all ozone is identical and there is no detectable formation of monatomic oxygen.

* Consultant, Westinghouse Electric and Manufacturing Company.

2. The Physics of Driving an Automobile. C. R. Fountain, *Amherst College.*—(Published in the *American Journal of Physics* **10**, 166 (1942).)

3. The Sabattier Effect. Nora M. Mohler, *Smith College.*—The recent publication[1] of a simple method for distinguishing between the external and internal photographic latent image has brought the study of several problems within the abilities of the senior honors student. The Sabattier effect, i.e., the effect of a diffuse exposure upon a developed but not fixed image, has been studied. Strips of contact printing paper were exposed with a step wedge, developed in glycine and fixed as usual, to show the surface image; if after the first development a silver bleach of sulfuric acid and potassium dichromate was used, redevelopment and fixation show the internal image. A reflection densitometer with a photovoltaic cell was used to find densities. The effect of varying the diffuse second exposures after the first development was studied. Comparison of the characteristic curves for the external and internal images with the corresponding results after the diffuse exposure show an increase in density of the external image nearly proportional to the number of the unaffected grains, accompanied by destruction of the internal image roughly proportional to its original density. A possible explanation on the Gurney-Mott[2] theory is suggested.

[1] Berg, Marriage, and Stevens, J. Opt. Soc. Am. **31**, 385 (1941).
[2] Gurney and Mott, Proc. Roy. Soc. **A164**, 151 (1938).

4. Edge Tones. Arthur Taber Jones, *Smith College.*—Increase in width of the wedge makes the sound louder, and extends downward the frequency limit for audible sound. With small upward velocities of the air sheet no low frequency sound is heard. With a wide wedge and a sufficient upward velocity lower pitched sounds are heard, and if the velocity exceeds a certain minimum value the low frequency limit for audibility seems to be independent of the velocity. With a wide wedge and a considerable velocity the fall in pitch that occurs with increase in slit-wedge distance may extend over several octaves and be free from discontinuities. Throughout this region the relation between frequency N and slit-wedge distance h is given approximately by $Nh^{1.45}=\text{const}$. By taking account of the Bernoulli increase in horizontal velocity in the constriction between slit and wedge, it is possible to account qualitatively for the above facts and for various others without having recourse to the vortices that are usually regarded as of primary importance.

5. Some Quasi-Hysteresis Cycles. Henry A. Perkins, *Trinity College.*—It is possible to carry a bar of wrought iron through a variety of cycles like those described in an article in *The Physical Review* of December 1, 1941.[1] These cycles, plotted on a B–H diagram, make use of both slow

and abrupt magnetization and demagnetization combined with both making and breaking a current sent longitudinally through the magnetized bar. There are actually 16 such cycles made by the various possible combinations and permutations of the different factors involved. Eight are narrow quadrilaterals with straight ends and curved sides, and eight are like an inclined figure 8 with straight ends. In all these cycles making or breaking the longitudinal current I results in a change of flux whose value and direction depends upon the manner of producing it. Invariably I (make or break) causes an increase in a slowly built-up flux and a decrease of residual flux after slow demagnetization. On the other hand I (make or break) decreases flux that was built up abruptly and increases it after abrupt demagnetization. The conclusion is that slow changes of flux lag, as would be expected, behind the stable state, while abrupt changes invariably overshoot the stable condition, and more so in magnetizing the iron than in demagnetizing it.

[1] H. H. Perkins and H. D. Doolittle, Phys. Rev. **60**, 813 (1941).

Proceedings of the American Physical Society

Minutes of the Meeting of the New York State Section held at Wells College, Aurora, New York, April 4, 1942

THE Spring Meeting and Biennial Election of the New York State Section of the American Physical Society was held at Wells College, Aurora, New York, on Saturday, April 4, 1942. An attendance of about 90 members and visitors was recorded. The following program of invited papers was presented:

Address of Welcome. President William E. Wold, *Wells College.*

Radioactive Tracers in Biological Research. LeRoy L. Barnes, *Cornell University.*

Cosmic Rays. Kenneth I. Greisen, *Cornell University.*

Glass Light Filters. O. A. Gage, *Corning Glass Works.*

Report of the A.P.T. Committee on the Teaching of Physics in Secondary Schools. H. A. Sherman, *Manlius School.*

University Defense Training. R. C. Gibbs, *Cornell University.*

Physics and Chemistry in Crime Detection. H. W. Rogers, *Colgate University.*

Following the meeting Professor Gaehr showed several interested teachers some of the demonstration experiments in his laboratory.

The following was the result of the election:

		Terms Expire
Chairman,	W. B. Rayton, *Bausch and Lomb Optical Company*	1944
Vice Chairman,	R. A. Patterson, *Rensselaer Polytechnic Institute*	1944
Secretary,	W. R. Frederickson, *Syracuse University*	1944
Treasurer,	G. H. Cameron, *Hamilton College*	1944
Members of the Executive Committee,		
	P. F. Gaehr, *Wells College*	1946
	H. P. Gage, *Corning Glass Works*	1946

The executive committee also includes three others whose terms expire in 1944: R. C. Gibbs, *Cornell University* (ex-chairman); E. L. Manning, *State Education Department;* and Mrs. M. Coutant, *Oneonta High School.*

P. R. Gleason, *Secretary*

Proceedings of the American Physical Society

Minutes of the Meeting of the Southeastern Section held at Oxford, Mississippi, April 10–11, 1942

THE eighth annual meeting of the Southeastern Section of the American Physical Society was held at the University of Mississippi, Oxford, Mississippi, on Friday and Saturday, April 10–11, 1942. Approximately one hundred members and guests attended the meeting. Local arrangements were made by a committee headed by W. L. Kennon.

The regular program consisted of twenty-two papers, abstracts for seventeen of which are appended hereto. Abstracts of other papers will be found in the August, 1942 issue of the *American Journal of Physics.* Other features of the program were a talk by J. C. Morris on "The Part of the Physicist in the Defense Program," a conference of department heads on current problems, and a

general conference on defense courses. The Section also participated in the formal opening of the University of Mississippi Observatory, at which D. V. Guthrie spoke on "Celestial Laboratories."

At the business meeting the election of the following officers for the year 1942–43 was announced: *Chairman*, W. L. KENNON; *Vice Chairman*, L. L. HENDREN; *Secretary*, E. SCOTT BARR; *Treasurer*, C. B. CRAWLEY; AND *Member of the Executive Committee*, A. W. DICUS.

The invitation extended by the Alabama Polytechnic Institute to hold its next meeting at Auburn, Alabama, was accepted.

E. SCOTT BARR, *Secretary*

ABSTRACTS

1. Ultraviolet Absorption Spectra of Some Sugars. W. C. BOSCH AND E. W. ANDERSON,[1] *Tulane University*.—The absorption spectra of aqueous solutions of ten monosaccharides and four disaccharides were studied in the region 200 to 400 mμ. The monosaccharide group included aldopentose, methyl-pentose, aldo-hexose, and keto-hexose types. The data indicate that absorption is shown by some sugars in the region of 280 mμ. As reported by other workers, sugars of the ketose type showed the most definite characteristic absorption. In general, the molecular extinction coefficients of sugars are low, being well below 10, and this suggests the possibility that absorption shown may be due to impurities. There is some evidence, however, to indicate that for certain sugars the bands should be attributed to the sugars themselves.

[1] Now at Ohio State University.

2. Photographic Effect of Zinc. PAUL S. DELAUP AND QUINTIN HOLDEMAN, *Southwestern Louisiana Institute*.—The darkening of a photographic film caused by a zinc plate placed near the film was investigated. By performing the experiment in a mine far below ground it was shown that the effect was not due to cosmic rays as had been suggested by another investigator. It was also shown that the effect was not due to impact of slow speed positive or negative particles.

3. The Infra-Red Absorption of Silver Cyanide. W. DAVID STALLCUP AND DUDLEY WILLIAMS, *University of Florida*.—The spectrum of powdered AgCN has been studied in the region 2500–1800 cm^{-1}. Intense absorption at 2178 cm^{-1} is attributed to an oscillation involving the CN group. The CN frequency for AgCN is almost 100 cm^{-1} higher than the CN frequencies of NaCN and KCN.

4. Space Group and Lead Positions in Lead Gluconate. R. PEPINSKY, *Alabama Polytechnic Institute*.—Lead gluconate, $Pb(C_6H_{11}O_7)_2$, crystallizes from water in pseudo-hexagonal plates which show Laue symmetry $D_{3d}-3\bar{m}$. c and a axis oscillations (15°) with Cu$K\alpha$ radiation show a trigonal cell, with $a=10.99$A, $c=47.18$A. The density 2.409 g/cc gives $Z=11.99\approx12$ molecules/cell. Indexed diagrams reveal: (0001) present only for $l=3n$; all odd layer lines on a-axis oscillations very faint; strong intensities for every third spot along most c-axis row-lines (h and k constant), weak third spots along remaining c-axis row-lines, with l indices of strong or weak spots varying with particular row-line. These variations can be accounted for only in space-group $D_3^4-C3_121$ (or enantiamorphous $D_3^6-C3_221$), with lead atoms on a lattice of half the true a-periodicity. Positions for lead atoms in true cell, as determined by intensity variations and symmetry, are:

0.2, 0, ⅓;	0, 0.2, ⅔;	0.3, 0.3, 0;
0.7, 0, ⅓;	0.5, 0.2, ⅔;	0.8, 0.3, 0;
0.2, 0.5, ⅓;	0, 0.7, ⅔;	0.3, 0.8, 0;
0.7, 0.5, ⅓;	0.5, 0.7, ⅔;	0.8, 0.8, 0.

Each lead is on a twofold axis, with its two gluconic residues extended above and below along the c direction, the disposition of these residues necessitating the large cell.

The material studied was furnished through the kindness of Dr. Horace S. Isbell of the National Bureau of Standards.

5. Thermal Diffusion Tube for Liquids. H. E. CARR, *University of South Carolina*.—A thermal diffusion tube has been constructed similar to that described by Korsching and Wirtz.[1] A rectangular groove, 1 meter long, 1.59 cm wide, and 0.023 cm deep, was milled down the middle of two brass strips, each $41\times1\frac{1}{2}\times\frac{3}{16}$ inches. These strips were clamped together, grooves facing, using No. 100 gauge Pliofilm as a gasket. Thus was formed a thin diffusion tube 1 meter long of rectangular cross section, 1.59×0.048 cm, into which liquids were introduced. A piece of channel brass, $41\times1\times\frac{1}{2}$ inches, was soldered to the back of each of the strips to serve as water jackets. By passing hot and cold water through these jackets the top side could be heated and the bottom cooled.

With 0.75 molar solution of $ZnSO_4$, tube slope of 53°, and temperature difference between strips of approximately 55°C, the concentration at lower end was doubled in 1½ hours. A 21-percent solution of sucrose increased to 26 percent at lower end in 2½ hours, using a temperature difference of about 50°C and tube slope of 25°. Curves showing separation obtained as a function of time, concentration, and slope of tube will be given.

[1] Korsching and Wirtz, Naturwiss. **27**, 367 (1939).

6. An Interpretation of Wave Mechanics. N. ROSEN, *University of North Carolina*.—If, in the Schrödinger wave equation for a single particle, the wave function ψ is written as $Ae^{iW/\hbar}$, where A and W are real functions, the equation splits up into two well-known equations.[1] One of them has the form of the equation of continuity for a fluid of density A^2 and velocity $\nabla W/m$. The other has the form of the Hamilton-Jacobi partial differential equation for the function W, with the potential energy V replaced by $V-(\hbar^2/2m)\nabla^2A/A$, however. These equations suggest

that the Schrödinger equation should be interpreted as describing a statistical ensemble of identical particles (of density A^2), each of which is moving along a definite path according to classical mechanics, its velocity being given by $\nabla W/m$. The particles of this ensemble interact with one another, the interaction being described by the term $-(\hbar^2/2m)\nabla^2 A/A$.[2] This interaction alters the motion of each particle. In this way one can account for the difference between the predictions of wave mechanics and of classical mechanics without giving up the particle picture in the former. The extension of this interpretation to the wave equation for more than one particle is obvious. One can interpret the Klein-Gordon and the Dirac equation (in the iterated form) in the same way, but the interaction term is different for each equation.

[1] Madelung, Zeits. f. Physik **40**, 322 (1927).
[2] E. H. Kennard, Phys. Rev. **31**, 876 (1928).

7. Quantum Mechanical Systems with Generalized Hamiltonians. NATHAN ROSEN AND ARTHUR E. RUARK, *University of North Carolina.*—In classical mechanics[1] it is shown that a Lagrangian $L(q, \dot{q}, \ddot{q}, \cdots, q^{(n)})$ for a system with one degree of freedom leads to the Hamilton equations. Let us write $q_1, q_2, \cdots, q_n$ for $q, \dot{q}, \cdots, q^{(n)}$, and let

$$p_1 = \partial L/\partial \dot{q} - (d/dt)\partial L/\partial \ddot{q} + \cdots - (-1)^n (d/dt)^{n-1} \partial L/\partial q^{(n)};$$
$$p_2 = \partial L/\partial \ddot{q} - (d/dt)\partial L/\partial \dddot{q} + \text{etc.}$$

Then $H(q_1, \cdots, q_n; p_1, \cdots, p_n)$ is $\Sigma p_i \dot{q}_i - L$. Thus, p_1 is not identical with the momentum occurring when $\ddot{q}$, etc., are absent from L. The Hamiltonian equations of motion are identical with those of a system possessing n degrees of freedom. To pass to quantum theory one may follow the usual procedure of writing down commutation relations between canonically conjugate variables:

$$p_i q_j - q_i p_j = \hbar/i,$$

with all other pairs of variables commuting. The extension to K degrees of freedom is obvious. The commutation relations lead to the result, at first sight surprising, that in such problems ordinary Cartesian coordinates and velocities commute.

This may have some bearing on the problem of electronic motion since Schott showed that on the basis of the Lorentz equations part of the stored-up energy is expressible as a term proportional to the square of the acceleration. However, this problem is complicated by the presence of radiation damping forces which cannot be described by a term in the Lagrangian.

[1] Whittaker, *Analytical Dynamics.*

8. Condensation Due to Adiabatic Compression. ARTHUR E. RUARK, *University of North Carolina.*—If saturated vapor is compressed isothermally, condensation will occur (neglecting supersaturation). If it is compressed adiabatically, the increase of temperature will ordinarily prevent condensation. The question arises, are there vapors which can condense under adiabatic compression? Treating the vapor as a perfect gas, the answer is, condensation can occur if

$$d \log p/dT < 1/T(\gamma - 1),$$

where p is the pressure of saturated vapor; T is absolute temperature; γ is the ratio of specific heats. Meteorology books state that descending air (presumably undergoing almost adiabatic compression) *never* produces fog. The above criterion supports this idea if the air is initially saturated, but for supersaturated air the conclusion may be questioned. From I. C. T. data, it appears that CCl_4 *above* about 70°C can condense under adiabatic compression; for the derivative above decreases rapidly as T increases. Trueblood[1] observed condensation on quickly compressing a cloud chamber containing air and CCl_4. This does not prove the existence of the phenomenon we are discussing because of the complicated conditions; Trueblood's vapor may have been supersaturated initially. However, our equation offers a partial explanation of his observation.

[1] Thesis, University of Washington, 1934.

9. Specific Surface Measurements on Compact Bundles of Parallel Fibers. R. R. SULLIVAN, *University of Tennessee.*—The equation for viscous flow of an incompressible fluid through porous media has been given[1] as

$$Q = (\zeta A/\mu k_0 S_0^2)(\epsilon^3/[1-\epsilon]^2)(\Delta p/L),$$

where Q is volume flow (cc/sec.), A is cross-sectional area of medium, μ is coefficient of viscosity, S_0 is specific surface (cm²/cc), and $\Delta p/L$ is pressure gradient, all in c.g.s. units. ζ is an orientation factor equal to unity for flow parallel to exposed surfaces. k_0 is a constant under certain circumstances. With stiff fibers all oriented parallel to flow, k_0 depends differently on ϵ, the porosity of the bundle, than with fibers perpendicular to flow, or randomly oriented. An experimental relationship between k_0 and ϵ is here given for parallel flow through bundles of roughly circular fibers for porosities from 0.09 to 0.9. Representative values are:

ϵ:	0.1	0.3	0.4	0.5	0.6	0.7	0.8	0.9
k_0:	0.8	0.9	1.0	1.2	1.4	1.7	2.3	3.4

These contrast with the approximately constant value 3.2 which persists over porosities from 0.28 to 0.87 for a wide range of perpendicularly and of randomly packed bundles of textile fibers, lead shot, glass beads, rings, saddles, and wire crimps.[2]

[1] R. R. Sullivan, J. App. Phys. **12**, 503 (1941).
[2] R. R. Sullivan and K. L. Hertel, *Advances in Colloid Science* (Interscience Publishers, Inc., New York, 1942), Vol. 1, pp. 37–80.

10. An Improved Procedure Used in the Measurement and Analysis of Some City Noises in New Orleans. D. S. ELLIOTT AND L. B. SCOTT,[1] *Tulane University.*—The main purpose of this study was to evolve improved methods and techniques for studying city noises. Beacuse of the inconstancy of many city noises, highly resolved frequency measurements are difficult to obtain, and single numbers for expressing intensity levels are inadequate for purposes of comparison.

For determining the manner in which, for a given noise, the intensities were dispersed, a special data sheet was designed which enabled a single observer to tabulate readings for sounds of rapidly varying intensities.

For determining the frequency characteristics, "noise samples" were recorded on a phonographic disk "in the field," and afterwards these were analyzed in the laboratory to a fairly high degree of resolution.

Results obtained from some sixty test measurements in actual field situations in New Orleans indicate the effectiveness of the methods.

[1] Now with the U. S. Armed Forces.

11. A Check on Film Speeds. E. C. LONG, *University of Georgia.* (*Introduced by R. H. Snyder.*)—Runs were made on Eastman and Agfa films, under controlled conditions of three speeds of films for white, green, blue, and red lights. Comparisons were first made with white light on Eastman Super XX for variations in individual rolls. Checks were then made on Eastman Super XX, Verichrome, and Panatomic X, and Agfa Superpan Press, Super Plenachrome, and Finopan for both colored and white light.

Development was then carried out on the whole group as a control measure. A comparison was then made of image on films and discrepancies in speeds ascertained.

This work was carried out under the supervision of Dr. R. H. Snyder.

12. An Adaptation of the Anderson Bridge for the Detection of Minute Changes in Temperature. W. L. KENNON AND A. B. CULLEN, *University of Mississippi.*—The particular arrangement of the bridge used in this work is, when nearly balanced, very sensitive to a slight change in the ratio of the condenser capacities. The condensers are constructed of thin-walled glass bulbs silvered on their inner and outer surfaces. A slight difference in the temperatures of the two condensers, owing to the temperature coefficient of the glass dielectric, changes the ratio of the capacities and unbalances the bridge.

For successful operation the bridge must be supplied with a very pure sinusoidal voltage of constant frequency. This is supplied by a specially designed oscillator controlled by a thousand-cycle tuning fork, which acts to control the frequency very much in the same way as a quartz crystal in a radiofrequency circuit.

A specially designed transformer circuit amplifies the output of the unbalanced bridge. The unbalanced condition is detected by an oscillograph.

The entire device is designed to replace the thermocouples previously used in the senior author's "null-method" for the exact measurement of the specific heats of liquids.

13. A Method of Preparing Gray Scales. E. S. BARR AND L. B. SCOTT,[1] *Tulane University.*—The scales discussed here are 10-cm strips of 35-mm film (and contact prints from these) which have a maximum blackening at one end and no blackening at the other, with the blackening varying uniformly between.

To prepare the strips it was necessary to provide illumination which varied uniformly in intensity between the ends of the strips. This was accomplished by use of a parallel beam of light and a curved supporting surface for the film, so oriented that one end of the strip was parallel and the other perpendicular to the beam.

The equation for a curve, the normal to which makes an angle with the X axis which obeys the condition that its cosine shall be proportional to the distance along the curve from the origin, was derived and plotted to the desired scale. A metal plate was cut to match this curve and mounted with suitable accessories for clamping the film and orienting the device in the light beam.

Exposures were made by use of a thin lens with a source formed by placing a pinhole in front of a sodium arc.

The testing of such strips and some of their applications will be discussed.

[1] Now with U. S. Armed Forces.

14. An X-Ray Analysis of the Time-Softening Property of a Lead-Tin Alloy. W. RICHARDSON, H. VANCE WHITE, AND BERTHA H. WEAVER, *Virginia Polytechnic Institute.*—Certain lead-tin alloys, which from their solubility properties would be expected to harden with age, have been found to exhibit the reverse property of *softening* as they age. The particular alloy investigated, 19 percent tin, 81 percent lead, cast in a cold mold and water quenched, was found to decrease in hardness over a period of eight to ten days, changing from 12 Brinell to less than 7 Brinell. X-ray diffraction patterns of the freshly cast alloy resembled those of pure lead except for a slight displacement of all lines, showing that the tin was in solid solution in the lead. On another pattern made a day later, however, the strongest of the characteristic tin lines made its appearance; and later the patterns included more and stronger tin lines. This was interpreted as evidence that tin was being precipitated from the solution. This conclusion was verified by tests which showed the electrical conductivity of the alloy to be increasing over a period of time corresponding to the softening period. The fact that precipitation and softening occur simultaneously here seems to be in opposition to the present theory of age-hardening which explains hardening as an effect of precipitation.

15.* Neoprene under Periodic Stress. MILTON L. BRAUN, *Catawba College.*—A small stationer's band made of neoprene was subjected to a periodic stretching stress applied slowly, and presumedly isothermally. The full stress was maintained for approximately fifty seconds of drift, and then isothermally withdrawn. After a similar fifty-second period for relaxation this sequence was repeated at the rate of thirty cycles per hour. The strain seems to follow very closely a power law for several score of cycles, after which there seems to be a transition into a similar law of lower degree or into some other function. Further work is in progress.

* Read by title only.

16.* Note on the Analysis of Single-Scattering Data. F. T. ROGERS, JR.,[1] *The University of Houston.*—When a

beam of particles is single-scattered by a definite volume of matter into a suitable detector, the angle between the incident- and scattered-beam center lines being ϕ, the following relation may describe the experimentally observed scattering quite closely for certain apparatus "geometries":

$$kF(\phi)=\int_{\phi-\epsilon}^{\phi+\epsilon} f(\theta)\sigma(\theta)d\theta. \quad (1)$$

Here $F(\phi)$ is determined directly by observations, $\sigma(\phi)$ is the scattering function for angle ϕ, $f(\theta)$ is a known function for a given apparatus, and k and ϵ are known constants for a given apparatus.

If $\sigma(\phi)$ is known at some $\phi=\Phi$, $\sigma(\phi)$ may be got at intervals of 2ϵ each way from Φ numerically from Eq. (1) by a very simple differential method:

$$\sigma(\phi-\epsilon)=\{f(\phi+\epsilon)\sigma(\phi+\epsilon)-k[dF(\phi)/d\phi]\}/f(\phi-\epsilon). \quad (2)$$

This process is often helpful in the analysis of experiments made at small scattering angles, especially when $\sigma(\phi)$ decreases rapidly with increasing ϕ.

* Read by title only.
[1] With the University of California (1941–1942), on leave of absence.

17.* The Infra-Red Fundamental of $C^{13}O^{16}$. R. T. LAGEMANN,[1] *Ohio State University.*—The infra-red absorption band of carbon monoxide at 4.66 microns has been re-examined using narrower slits, smaller intervals of reading, and a replica grating of 2887 lines per inch in the second order. These improvements have resulted in the observation of more than twenty well-resolved lines due to the $C^{13}O^{16}$ molecule. The lines of the isotopic molecule are interspersed among those of the $C^{12}O^{16}$ molecule, which has been observed previously. The experimental band center displacement is in good agreement with the expected one, as computed from the isotopic masses of the carbon. The average line separation is about 3.6 wave numbers.

* Read by title only.
[1] Now at Emory University.

Proceedings of the American Physical Society

MINUTES OF THE MEETING OF THE OHIO SECTION HELD AT GRANVILLE, OHIO, APRIL 18, 1942

THE eighth meeting of the Ohio Section of the American Physical Society was held on April 18, 1942, at Denison University, Granville, Ohio. The meeting was in joint session with the Ohio Academy of Science. Fifty members and guests were present. The following eight papers were presented; of these the abstracts of four are appended.

Newly elected officers of the Section for the season 1942–43 are the following: H. V. KNORR, *Chairman;* PAUL B. TAYLOR, *Vice Chairman;* RICHARD H. HOWE, *Secretary-Treasurer.*

RICHARD H. HOWE, *Secretary*
Denison University, Granville, Ohio.

PROGRAMME

Physics Lecture Room, Barney Science Hall, 10:00 A.M.

1. **Further Order-Disorder Studies in the Case of Certain Spinels.** F. C. BLAKE, *Ohio State University.*

2. **A Mechanical Method for testing Shutter Speeds of Cameras.** GEORGE MOTT AND GEORGE MAYHEW (Introduced by C. W. Jarvis), *Ohio Wesleyan University.*

3. **The Chemiluminescence Spectrum of Chlorophyll *a*.** ALBERT STEWART, H. V. KNORR, and V. M. ALBERS, *Kettering Foundation, Antioch College.*

4. **Some Observations on a Dynamic Coulometer.** THOMAS BUCK (Introduced by P. E. Martin), *Muskingum College.*

5. **A Spark Recording Apparatus for Simple Harmonic Motion.** RALPH KRONE AND H. V. KNORR, *Antioch College.*

6. **Establishing and Maintaining a Color Temperature scale.** W. E. FORSYTHE, *General Electric Company, Nela Park.*

7. **The Absorption Spectrum of *ms*-Tetra-4-Dimethylaminophenyl Porphine.** DAVID FRY, *Ohio State University and Kettering Foundation, Antioch College,* V. M. ALBERS, and H. V. KNORR, *Kettering Foundation, Antioch College.*

8. **Radioactive Tracers in Industrial Research** (Invited Paper), MARTIN S. MAIER, *Battelle Memorial Institute.*

Luncheon, Curtis Hall Dining Hall, 12:30 P.M.
Annual Business Meeting.

1. Further Order-Disorder Studies in the Case of Certain Spinels. F. C. BLAKE, *Ohio State University.*—Following up the paper reported at the Chicago meeting of the Physical Society[1] the mechanics of finding correct atomic positions to lead to sub-microscopic twinning are carried to completion. The theoretical aspects of transitions from microscopic to macroscopic twinning are discussed and a classification of the several kinds of sub-microscopic twinning possible is given.

[1] Phys. Rev. **61**, 108 (1942).

2. The Chemiluminescence Spectrum of Chlorophyll *a*. ALBERT STEWART, H. V. KNORR, and V. M. ALBERS, *Kettering Foundation, Antioch College.*—The chemiluminescence spectrum obtained by quickly heating a solution of chlorophyll *a* in tetralin to 180°C has been measured photographically. The plate was calibrated and standardized using a standard lamp and neutral screens and the relative intensities calculated. These showed a band with a maximum at 677.5 mμ. The fluorescence spectrum was measured just after the chlorophyll *a* was dissolved in the tetralin at room temperature and again after the solution had been boiled five minutes. The band for the fresh material has a maximum at 688.5 mμ while the band for the reacted material is decreased to one-third the intensity of the former and has its maximum at 671.0 mμ. The chemiluminescence band is much narrower than the envelope of the two fluorescence bands when all three are plotted with the same maximum intensity, suggesting that only a fraction of the reactions are responsible for the chemiluminescence. The absorption spectrum of the reacted material differs from that of the fresh material in the intensity and position of the bands, especially in the violet region.

3. A Spark Recording Apparatus for Simple Harmonic Motion. RALPH W. KRONE AND H. V. KNORR, *Antioch College.*—An apparatus has been constructed with which the characteristic properties of simple harmonic motion can be investigated. The positions of a simple pendulum, 263 cm long and swinging with an amplitude of 28 cm, are recorded by means of a synchronous spark timer. A spark passes every twelfth of a second between the pendulum and a sheet of brass having the same radius of curvature as the path of the pendulum. The recording paper is placed upon the brass plate. By means of an induction motor, and a proper gear reduction the brass plate carrying the recording paper is moved in a horizontal plane perpendicular to the direction of vibration of the pendulum. Six complete periods can thus be recorded. The values obtained for the displacement, the velocity, and the acceleration are accurate to one percent. Values obtained for the period from the displacement-time graph check within one-tenth of one percent with the values found by direct observation and the theoretical formula.

4. Absorption Spectra in the Visible of *ms*-Tetra (3′, 4′-methylenedioxyphenyl) Porphine of HCl No. 4 and Three of Its Metal Complex Salts. DAVID FRY, *Ohio State University and Kettering Foundation, Antioch College,* V. M. ALBERS, AND H. V. KNORR, *Kettering Foundation, Antioch College.*—The absorption spectra of *ms*-tetra (3′, 4′-methylenedioxyphenyl) porphine of HCl No. 4 and its Ni, Zn, and Ag metal complex salts in benzene were measured in the region between 700 and 370 mu. All compounds gave a good chemical analysis except the silver salt which showed that the molecule contained one atom of silver and one molecule of pyridine. The absorption coefficients were calculated from Beers law. The instrument used was the Albers-Knorr spectroradiometer.[1] The spectra were compared with the corresponding *ms*-tetraphenylporphine spectra. The differences between the *ms*-tetra (3′, 4′-methylenedioxyphenyl) porphine and its salts spectra and the *ms*-tetraphenylporphine and its salts spectra[2] are slight. In comparing the two parent compounds, all the bands in the former are shifted 5 or 6 mu towards the red when compared with the latter. Also the absorption coefficients of all the bands, except the one at 649 mu, of the former are greater than those for the latter. The positions of the bands in mu and the value of the absorption coefficients $\times 10^{-2}$ for *ms*-tetra (3′, 4′-methylenedioxyphenyl) porphine of HCl No. 4 are as follows: 649—100; 595—133; 555—230; 518—440; 486—114; 425—8880.

[1] V. M. Albers and H. V. Knorr, J. Opt. Soc. Am. **28**, 121 (1938).
[2] V. M. Albers and H. V. Knorr, J. Chem. Phys. **9**, 497 (1941).

Proceedings of the American Physical Society

MEETING AT BALTIMORE, MAY 1–2, 1942

THE 248th meeting of the American Physical Society was held in Baltimore at the Johns Hopkins University on Friday and Saturday, the 1st and 2nd of May, 1942. The breach with the tradition of meeting in Washington at this time of year, which was enforced by the circumstances of the war, was surely unwelcome to many; but the quality of the hospitality offered by the Johns Hopkins University and by the Local Committee (Chairman, J. C. Hubbard) must have abolished nearly all the regrets. The number of contributed papers was much smaller than in previous years, showing all too clearly the claims of the war upon the time and occupations of physicists; but the attendance had not fallen off in so great a ratio (there were 328 who registered) and it was evident that the meeting offered a welcome opportunity for many a conference both formal and informal. The reduction in the number of papers brought the advantage that only on one half-day was it necessary to schedule simultaneous sessions. The abstracts of the contributed papers are appended; No. 5 and No. 41 were read by title.

The dinner of the Society was held on Friday evening at the Lord Baltimore Hotel, President

Bridgman presiding. It was distinguished by the presentation of the Duddell medal of the Physical Society (of Great Britain) to W. D. Coolidge of the General Electric Company. The medal was presented by Viscount Halifax, British Ambassador to the United States, with a felicitous speech; Lord and Lady Halifax were guests of the Society at the dinner. The presentation was followed by the response of Mr. Coolidge and preceded by an address of welcome from President Bowman of Johns Hopkins University and by an address by R. W. Wood. The speeches of Viscount Halifax and Mr. Coolidge are to be published probably in one of the journals under the supervision of the American Institute of Physics. A telegram was sent to J. S. Ames, former President of the Society, expressing the regret of the members at his enforced absence.

The Council met on Friday morning. It elected to Membership in the Society 59 candidates, and advanced two Members to Fellowship; their names are given hereinafter. J. H. Van Vleck and William V. Houston were appointed as representatives of the Society on the Division of Physical Sciences of the National Research Council to succeed E. U. Condon and H. D. Smyth. H. L. Curtis and Leigh Page were appointed to succeed themselves as liaison representatives of the Society on the Committee on Basic Sciences of the American Institute of Electrical Engineers. The Director of the American Institute of Physics was requested to distribute yearly to the members of the Society a brief account of the activities of the Institute, and this will be done.

The Society has lost through death the following members: Frederick Curtice Davis, who was lost in action in the Pacific theater early in the war, the first of our members to die in the service of the Nation; Carl Pfanstiehl of the Pfanstiehl Chemical Company; Sir William Bragg (Honorary Member) whose celebrity needs no further attestation in this place.

Elected to Fellowship: C. T. Lane and T. D. Poulter. *Elected to Membership:* George Antonoff, Norman W. Arnold, Carl L. Bailey, Edgar E. Barr, George Harold Best, Howard W. Brackney, Ellis E. Bray, John Edward Brolley, Jr., Albert Burris, Esther M. Conwell, Victor B. Corey, James Willson Ford, James W. Follin, Jr., Stanley M. Forman, J. L. Fowler, Ernest Frank, Norman L. Fritz, Charles J. Gallagher, Frank P. Goeder, Charles Franklin Hadley, Henry B. Hanstein, Arthur A. Hauser, Jr., Robert Darrow Heidenreich, L. Burton Hitchcock, Calvin H. Hogg, Chao-Wang Hsueh, Mark Gordon Inghram, Irving Kaplan, Raymond I. Lawley, Melvin Lax, Howard Allen Leiter, Saul Levy, Henry Lisman, John S. McCartney, Wilkison W. Meeks, David Middleton, Mark Muir Mills, James J. Murray, Glenn L. Musser, Glen Oneal, Jr., Shiao-Thur Pan, James Reid Patterson, Horst Poehler, Philip J. Rice, Jr., James Austin Richards, Jr., Sloan D. Robertson, Edith Lou Rovner, Morris Herbert Shamos, H. Guyford Stever, Elmer Eugene Stickley, Richard H. Stokes, Alfred M. Suggs, Robert Ambrose Thornton, Franz Orbach, Evans Vaughan, Robert H. Vought, Phillip R. Wallace, Irving Weiner, and William E. Wolstenholme.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University

ABSTRACTS OF CONTRIBUTED PAPERS

1. Covariant Representation of Five-Dimensional Field Theories. PETER G. BERGMANN, *Black Mountain College.*—To compare the five-dimensional and projective field theories proposed by Kaluza,[1] Veblen and Hoffmann,[2] Pauli,[3] and Einstein and collaborators[4] with each other, it is useful to develop a covariant formalism applicable to all of them. If one introduces in a five-dimensional Riemannian space with coordinates ξ^ρ a set of four parameters $x^\sigma(\xi^\rho)$, then it is possible to identify each curve x^σ=constant in the five-dimensional space with a "point" in a symbolic four-dimensional space. A complete tensor algebra and analysis can be constructed in this space of the x^σ. The four-dimensional metric is related to the five-dimensional metric, and the same is true of Christoffel symbols and curvature tensors. It turns out that, from this point of view, the theory of Kaluza and the projective theories are equivalent, while the theories of Einstein, Bargmann, and Bergmann are more general.

[1] Kaluza, Sitz. Preuss. Akad. Wiss. (1921), p. 966.
[2] Veblen, *Projektive Relativitätstheorie* (Berlin, Springer, 1933).
[3] Pauli, Ann. d. Physik **18**, 305 (1933); **18**, 337 (1933).
[4] A. Einstein, Ann. Math. **39**, 683 (1938); *Th. v. Kármán Anniversary Volume* (Pasadena, 1941), p. 212.

2. On the Quantization Problem in Hydrodynamics. L. TISZA, *Massachusetts Institute of Technology.*—The problem of liquid helium has been recently attacked by Landau[1] from an entirely new viewpoint. While there is hardly any doubt that the problem has to be treated on

the lines advanced by Landau, his development of *quantum hydrodynamics* does not seem quite satisfactory. It is suggested to start rather from classical hydrodynamics and restrict the modes of internal motion of the perfect liquid by quantum conditions. This leads (1) to longitudinal phonons, (2) to vortex rings with quantized angular momentum $\frac{1}{2}M\Gamma = Jh$, where M is the mass of the vortex ring, $\Gamma = \oint v ds$ the circulation, both constant according to classical theorems; J is a quantum number taking discrete, but not necessarily integer values. M varies for the different vortex rings from a minimum value compatible with the corpuscular structure of the liquid to a maximum value determined by the geometry of the container of the liquid. It will be shown that the thermo- and hydrodynamical properties of this system correspond to those of liquid helium. The results agree only partly with those of Landau. The reasons for the discrepancies and the experiments supporting the present theory will be discussed.

[1] L. Landau, Phys. Rev. **60**, 356 (1941), J. of Phys. **5**, 71 (1941).

3. Magnetic Force of Charge on Charge. F. W. WARBURTON. *Illinois Institute of Technology.*—The Riemann force of charge on charge satisfies not only the unipolar induction experiment with the rotating solenoid but also that for the rotating magnet. The high velocity term in the centripetal acceleration of the electron averaged over a circular orbit, balances the average value of another term in velocity of the electron. When the magnet rotates, the Coriolis acceleration term for an electron in an orbit, expressed in terms of the vector potential and integrated for the magnet, balances the relative motional term. The correction term in mutual force corresponding to relativistic increase in mass, although vanishing for a closed circuit, looms large for a massive body near a conductor whether or not the body is magnetic or rotating.

4. A New Method for Deriving Poynting and Other Valid Energy Flow Vectors. J. SLEPIAN, *Westinghouse Research Laboratories.*—A thin shell space enclosing a portion of an electromagnetic field is imagined suddenly created, and charges, electric and magnetic dipoles are introduced along the inner and outer shell surfaces and moved about so as to keep the field within the shell space itself, zero, and the field enclosed by the shell, the same, for sometime, as it would have been if the shell had not been created. The work done upon the moving charges and dipoles is defined to be the flux of electric energy out from the enclosed electromagnetic field. This work can be assigned to the elements of the enclosing surface in various ways—one yielding the Poynting vector, and the others yielding other valid energy flow vectors having the same divergence as the Poynting vector. If a spatially distributed stored energy density is also assigned to these charges and dipoles, then valid energy flow vectors are obtained which differ from the Poynting vector even in their divergence. These valid energy flow vectors assign an energy density in space differing from but equally valid with usual spatial energy density postulates.

5. Theoretical Half-Lives of RaE and P^{32}. E. GREULING, *Indiana University.*—It has been shown[1] that the asymmetric energy distribution of RaE electrons can be accurately predicted by the "second forbidden" tensor or polar vector interactions if the transition corresponds to no parity change with a spin change, $\Delta J = 2 \rightarrow 0$. The correct energy distribution *and the observed half-life* can be obtained concurrently if the magnitudes of the nuclear matrix elements, constructed from certain irreducible tensors, are estimated by a simple averaging process. Agreement with experiments is given by the tensor interaction with the reasonable assumptions: (1) The velocity of nuclear particles, $v \approx 1/6C$, and (2) The Fermi constant, $g \approx 4.6 \times 10^{-12}$. The observed energy distribution of P^{32} electrons cannot be accurately predicted in any "forbidden" approximation. The ratio of the nuclear matrix elements assumed[1] in order to fit Lawson's data at two points, corresponds to an unreasonably small nuclear velocity, $v \approx 0.03C$, and yields a half-life ~ 100 times too large in the "second forbidden" approximation. For $v \geq 1/10C$ the spectrum predicted differs very little from that given by the "first forbidden" tensor interaction with $\Delta J = 2 \rightarrow 0$. This transition, $P^{32}_{odd} \rightarrow S^{32}_{even}$, yields the correct half-life when $g \approx 2.1 \times 10^{-12}$ is assumed. In view of the fact that the energy distribution favors only slightly the "second forbidden" approximation, the evidence of the half-life indicates that P^{32} is probably "first forbidden" according to Gamow-Teller selection rules.

[1] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. **60**, 308 (1941).

6. Electric Quadrupole Moments of Light and Heavy Nuclei. S. B. WELLES, *Yale University.*—From the results of Feenberg and Wigner[1] for the wave function and term character of the ground state of light nuclei in the Hartree Model, and from the results of Rose and Bethe[2] for the corresponding nuclear spins, the electric quadrupole moments of these nuclei have been computed. In units of 10^{-26} cm^2, they are $Li^{6,7,8}$ 0, -2.7, 1.4; $Be^{7,8,9}$ -3.6, 0, 2.1; $B^{9,10,11,12}$ -0.6, 0, 0.7, -3.8; $C^{11,12,13}$ -2.4, 0, 0; $N^{13,14,15}$ 0, 0, 0; and $O^{15,16}$ 0, 0. A theoretical investigation of the quadrupole moments of heavy nuclei as a function of nuclear spin reveals certain regularities if it is assumed that the asymmetrical charge distribution is due to only one proton. No restrictions as to the type of coupling are included.

[1] E. Feenberg and E. Wigner, Phys. Rev. **51**, 95 (1937).
[2] M. E. Rose and H. A. Bethe, Phys. Rev. **51**, 205 (1937).

7. On the Magnetic Moments of H^3 and He^3. R. G. SACHS AND JULIAN SCHWINGER, *Purdue University.*—The magnetic moments of the light nuclei constitute a source of information concerning the extent to which spin conservation laws are relaxed in many-body systems. The sum of the moments of two nuclei which can be obtained from each other by an interchange of neutrons and protons has a particularly simple interpretation since it depends only on the amount of admixture of the possible LS states. Of this class of nuclei, H^3 and He^3 are of particular interest since the magnetic moments of both can pre-

sumably be measured. The theoretical value of the sum of their moments is

$$\mu_{H^3}+\mu_{He^3}=\mu_n+\mu_p-\tfrac{3}{8}(\mu_n+\mu_p-\tfrac{1}{2})(3^4D+2^2P-^4P),$$

where the state symbols indicate the probability that the system be found in the corresponding state. It is likely that the ground states of these nuclei are predominately $^2S+^4D$ and thus, if $^4D=5$ percent, $\mu_{H^3}+\mu_{He^3}=0.841$ nuclear magneton, which is to be contrasted with the deuteron moment (0.857), the expected theoretical value if $L-S$ coupling holds rigorously. The moments of the individual nuclei depend on the detailed structure of the ^4D function but if a particularly simple form[1] is assumed one finds

$$\mu_{H^3}=\mu_p-\tfrac{3}{8}(2\mu_p+\mu_n-\tfrac{1}{2})^4D,$$

whence $\mu_{H^3}=2.68$ and $\mu_{He^3}=-1.84$.

[1] E. Gerjuoy and J. Schwinger, Phys. Rev. **61**, 138 (1942).

8. On the Algebraic Theory of Higher Spins. M. DRESDEN, *University of Michigan.*—It has been shown that particles of spin 0, ½, 1, can be described by a set of linear equations of the Dirac type. An attempt to a possible extension of this type of equation has been made. The method starts, using a method of factorization due to Rainich,[1] by obtaining all possible commutation relations which will insure that the second-order wave equations are satisfied by each wave function as a consequence of the first-order equations. This is done by writing down the conditions on the coefficients for the splitting of a quadratic form into 2 linear forms, then the condition for the splitting of a quadratic form in a linear and a quadratic form and so on. The general relations are of the form $\Sigma_P \beta_{n_1}\beta_{n_2}\cdots\beta_{n_s}=\Sigma_P \delta_{n_1 n_2}\beta_{n_3}\cdots\beta_{n_s}$. They allow many special solutions among others the Dirac and Duffin relations. The next complicated will be presented and its physical contents discussed.

[1] G. Y. Rainich, Bull. Am. Math. Soc. **48**, No. 1, p. 41.

9. The Magnetic Current in Gases. FELIX EHRENHAFT.—In analogy with the definition of the electric ion a magnetic ion is a body which moves in a *homogeneous* magnetic field in the direction of the lines of force, reverses its direction of motion with the reversal of this field, etc. A magnetic current consequently is the movement of magnetic ions in the homogeneous magnetic field. To this extension of physical conceptions the author has been forced since he observed movements in homogeneous magnetic fields which hitherto were unknown. In an homogeneous magnetic field *some* particles of various finest metal powders, especially such of ferromagnetic elements, move from one homogeneous magnetrode (the plate of a magnetic condenser) to the opposite one, while the others remain at rest. A particle suspended in gas irradiated by light moves in the homogeneous magnetic field in the lines of force and reverses its direction with the reversal of the field. The determination of the charge on these ions and the change of charge on them are discussed. The author has made these experiments in cooperation with L. Banet. He restricts himself to the reports of the investigations on gases while the latter will report about the movements in liquids, and give some references.

10. The Magnetic Current in Liquids. LEO BANET. (*Introduced by Felix Ehrenhaft.*)—The above-given definitions of magnetic ions and magnetic currents can also be applied to movements in liquid mediums. The following observations have been made: Colloidal particles of nickel[1] are deposited equally on two homogeneous (gold-plated) magnetrodes.—Single particles of these colloids can be observed moving toward the magnetrodes by means of a microscopic arrangement. Some particles of finest metal powders move in the homogeneous magnetic field toward the magnetrodes in various liquids. These movements cease instantly if the magnetic field is shut off and start just the same way.

[1] F. Ehrenhaft, Anzeiger d. kais. Akad. d. Wiss. Wien **18** (July 10, 1902); Phil. Mag. **11**, 140 (1931); Ann. d. Physique **13**, 151 (1940); J. Frank. Inst. **230** 381 (1940); Phil. Sci. **8**, No. 3 (1941); Science **94**, 232 (1941); J. Frank. Inst. **235** (March, 1942); F. Ehrenhaft and L. Banet, Phil. Sci. **8**, No. 3 (1941); J. C. Maxwell, *Treatise*, art. 377–379 (Oxford, 1902).

11. The Characteristic Radiations of CO^{60}. MARTIN E. NELSON, M. L. POOL, AND J. D. KURBATOV, *Ohio State University.*—The 10.7-minute Co^{60} was produced by a $Co(d, p)$ reaction in an intensity several thousand times that obtained from $Co(n, \gamma)$ and $Ni(n, p)$ reactions. Ionization chamber measurements indicated that approximately one gamma-ray was emitted for each beta-ray. The lead absorption coefficient for the gamma-ray activity was 0.58 cm^{-1}, corresponding to an energy of 1.5±0.2 Mev. The beta-rays were measured with a magnetic beta-ray spectrometer and were found to be continuous. Allowing for the slight tail due to gamma-ray recoils the endpoint was measured at 1.35±0.1 Mev. This is probably an allowed transition. The 5.3-year Co^{60} was produced by a $Co(d, p)$ reaction. Chemical separations removed the long life impurities. Absorption measurements, in agreement with those previously reported,[1,2] indicated the presence of a 1.7±0.2 Mev gamma-ray and a 220±20 Kev beta-ray. However, no higher energy electrons were observed. From these data it seems evident that an isomeric transition between the 11-minute and 5.3-year periods does not occur but that the activities decay independently. An energy level diagram summarizing the data will be shown.

[1] J. R. Risser, Phys. Rev. **52**, 768 (1937).
[2] J. J. Livingood and G. T. Seaborg, Phys. Rev. **53**, 847 (1938).

12. Photoneutrons Produced in Beryllium by the γ-Rays of Radio-Antimony (60 d). G. STANLEY KLAIBER AND GERTRUD SCHARFF-GOLDHABER, *University of Illinois.*—Previous work[1] has shown, that the energy of neutrons generated in Be by the hard γ-rays of RdY (100 d) is equal to that of RdTh+D neutrons (220 Kev). This result was obtained by counting the proton recoils produced by the photoneutrons in a hydrogen filled ionization chamber as a function of the discriminator voltage. From the photoneutron energy the energy of the γ-ray can be calculated (1.87 Mev). Now this work has been extended to the γ-ray of Sb^{124} (60 d). A sample of a few millicuries

of Sb^{124} was kindly produced for us by Dr. Kamen by bombarding antimony with deuterons in the Berkeley 60-inch cyclotron. Proton recoils due to photoneutrons from $Sb^{124}+Be$ were observed and their distribution in energy measured. The arrangement was calibrated by means of a pulse generator and a value of 115 ± 20 Kev for the $Sb^{124}+Be$ neutrons was obtained. This leads to an energy of 1.75 Mev for the γ-ray emitted by Sb^{124}. Mitchell *et al.*[2] obtained for this γ-ray a value of 1.82 Mev from Compton electrons.

[1] G. Scharff-Goldhaber, Phys. Rev. **59**, 937(A) (1941).
[2] A. C. G. Mitchell, L. M. Langer, and P. W. McDaniel, Phys. Rev. **57**, 1107 (1940).

13. Collision Cross Sections of C and H for 25-Mev Neutrons. R. SHERR, *Harvard University.*—Lithium bombarded with 10.2-Mev D^+ ions is known to yield neutrons with a maximum energy of 25.4 Mev. The reaction $C^{12}(n, 2n)C^{11}$ provides an energy-sensitive detector with calculated threshold at 20.6 Mev. By placing graphite at different angles with respect to the direction of the deuteron beam, it was found that the 20.5 min. C^{11} activity decreased rapidly with falling neutron-energy and was gone at 21.5 Mev. For the scattering experiment, the effective area of the Li target was 2.0×0.3 cm²; the target detector separation was 22 cm; the graphite detector was 4.5 cm long with a cross section of 1.9×1.6 cm² facing the target. The scatterers of graphite and paraffin were rectangular blocks with cross section 2.54×2.54 cm² placed midway between target and detector. Tests indicated negligible effect due to neutrons scattered by the cyclotron and water tanks. The collision cross sections did not vary for transmissions from 40 percent to 70 percent and were found to be 0.39×10^{-24} cm² for $n-p$ and 1.05×10^{-24} cm² for $n-C$, to an estimated accuracy of 10 percent. These values will be somewhat increased by appropriate corrections for geometry.

14. The Origin of Statistical Fluctuations in Proportional Geiger Counters. W. F. G. SWANN, *Bartol Research Foundation of the Franklin Institute.*—In a proportional Geiger counter 25 cm long filled with argon at 40-cm pressure, something like 700 ions would be produced in the whole path length. If all of these were produced as single pairs by the original cosmic rays, there would be no basis for appreciable fluctuation. However, the theory of ionization results in a very appreciable fraction of the measured ionization coming from acts in which the ion originally ejected has enough energy to produce many ions. The number of these acts is sufficiently small to be affected by statistical fluctuations, but the ions associated with them are sufficiently many to make those fluctuations affect a large portion of the total ionization. The paper will give the details concerning these matters.

15. Pulse Size as a Function of Pressure in Geiger-Mueller Counters. CARLTON W. MILLER AND C. G. MONTGOMERY, *Yale University.*—A vacuum tube circuit was used to measure the size of the pulses from a Geiger-Mueller counter which was over-shooting. This was done in the pressure range from two centimeters to thirty centimeters of mercury for the gas mixtures 90 percent argon, 10 percent hydrogen; 90 percent neon, 10 percent hydrogen; 90 percent helium, 10 percent hydrogen; and for 100 percent hydrogen—all of tank purity. Since the pulses were observed to have distribution in size, sufficient measurements were taken to give information concerning the variation of this distribution with pressure and voltage. The 100 percent hydrogen gave the greatest pulse size observed (900 volt pulses at pressure equal to 30 cm Hg and at an over-voltage of 500 volts), with the mixtures giving pulses of lesser size in the same order as they are listed above. In each case, as the pressure was lowered, the pulses were larger at the lower over-voltages. The width of the plateau decreased as the pressure was lowered, making extensive measurements at low pressures impossible. Graphs of the data are presented, showing pulse size as a function of pressure and voltage, and the variation of the size-distribution. The accuracy of the measurements is discussed.

16. Production of Penetrating Particles in the Cosmic Radiation. VICTOR H. REGENER, *University of Chicago.*—The production of penetrating particles in 5 and 10 cm of lead, iron, carbon, aluminum, and paraffin was investigated at Climax, Colorado (3500 m) in January, 1942. The altitude dependence of the production in lead was measured between Climax and Chicago. The apparatus consisted of several counter trays between layers of absorbing material and yielded simultaneously cross section and multiplicity for the production, as well as the absorption of the produced particles. The production of penetrating particles by a non-ionizing component of the cosmic radiation here considered is of the multiple type and differs from the production of soft mesotrons by photons. The material-dependence of the production rate shows per g/cm² of producing material an inverse trend with the atomic number; this inverse z dependence and the high rate of production make it necessary to introduce appreciable corrections for lifetime measurements of the mesotron where an absorber of dense material is used to compensate for the absorption in air between stations at different altitude. The absorption coefficient in lead of the produced particles depends on the atomic number of the material where the production took place.

17. Further Measurements of the Mesotron Lifetime. BRUNO ROSSI AND KENNETH GREISEN, *Cornell University,* JOYCE C. STEARNS, DAROL K. FROMAN, *University of Denver,* AND PHILLIPP G. KOONTZ, *Colorado State College.*—New experiments have been performed in order to test the theoretical relation between momentum and average range before decay of mesotrons and to determine more accurately the value of the proper lifetime. Differential absorption measurements of mesotrons have been carried out with an anti-coincidence method, at Denver (1616 m above sea level) and at Echo Lake (3240 m above sea level). The experimental results yield the differential momentum spectrum of mesotrons at Echo Lake from 3×10^8 to 1.2×10^9 ev/c, and enable one to calculate the probability of survival between Echo Lake and Denver

for two fairly monoenergetic mesotron groups. The average effective momenta of these groups are $p_a = 5.15 \times 10^8$ and $p_b = 9.72 \times 10^8$ ev/c, respectively. The corresponding average ranges before decay, as deduced from the probabilities of survival, are $L_a = (4.26 \pm 0.46) \times 10^5$ cm and $L_b = (8.5 \pm 1.9) \times 10^5$ cm. Thus, within the experimental errors, the average ranges are in the same proportion as the momenta, in agreement with the prediction based on the relativistic transformation of time intervals. From the above measurements and with a mesotron mass of 10^8 ev/c^2, one obtains the value $\tau_0 = 2.8 \times 10^{-6}$ sec. for the proper lifetime of mesotrons.

18. The Energy Distribution in Showers at Low Energies. J. A. RICHARDS, JR. AND L. W. NORDHEIM, *Duke University.*—A numerical method for the calculation of the energy distribution in showers is developed. It consists of a series of successive approximations which permit one to continue the known asymptotic functions at high energies towards lower energies. In this way the track length distributions for electrons and photons in high energy showers have been calculated for both air and lead down to an energy of about 4 Mev. Close approximations to the true probabilities for the radiative effects have been used at all energies and Compton effect and collision secondaries have been fully taken into account. The electron distribution increases logarithmically at very low energies and can be extrapolated to obtain the total track length of particles of all energies. The value thus obtained agrees very closely with the value following from energy considerations.

19. Theory of the Lateral Spread of Cosmic-Ray Showers. JANE ROBERG, *Duke University. (Introduced by L. W. Nordheim.)*—Following the procedure of Nordheim,[1] a systematic method is developed to calculate the mean square angular and lateral spreads of shower particles of all energies to any desired accuracy. An analytical solution, which takes the effect of ionization into account, is found for high energies, while for lower energies a method of successive approximations can be carried through numerically. These more precise calculations confirm previous estimates and show that Auger's observations on large air showers can be accounted for by the theory.

[1] Nordheim, Phys. Rev. **59**, 929A (1941).

20. Replica Gratings for Large Schmidt Telescopes. R. W. WOOD, *The Johns Hopkins University.*—Grating replicas have been mounted in mosaic form on a glass disk 18 inches in diameter for the 18-inch Schmidt telescope at Mt. Palomar, California. The elementary replicas measure 4×6 inches, and for the blue and violet region over 95 percent of the light is in the first-order spectrum and less than 1 percent in the central image. There are only 800 lines to the inch, as very short spectra are required for spectral classification of very faint stars in rich fields to prevent overlapping. A similar 18-inch grating with 1500 lines to the inch has been made which enables one to distinguish between novae and planetary nebulae, the latter giving a nitrogen band very near the bright hydrogen line. This grating gives the highest intensity in the red region. The objective prism is unable to resolve the two lines. Lantern slides, experiments, and exhibits.

21. Hyperfine Structure of the Forbidden Line λ2967.52 of Hg I. S. MROZOWSKI, *University of Chicago.*—The structure of the forbidden mercury line λ2967.52 ($6^3P_0 - 6^1D_2$) was investigated in the third order of each of two 30-foot Chicago gratings. The current of a powerful watercooled mercury arc was correspondingly adjusted so as to produce a relative weakening by reabsorption (end-on observation) of the very strong neighboring line λ2967.28 ($6^3P_0 - 6^3D_1$). Four sharp components were observed in the forbidden line: 0 (10), +0.553 (5), +0.828 (4), and +1.048 cm^{-1} (<1); the intensities given in parenthesis are values estimated on a scale of 10. The structure observed agrees very closely with that predicted for this line by Goudsmit and Bacher[1] several years ago. Hence the first component is emitted by Hg^{199} and the remaining three by Hg^{201}. The forbidden line has an electric dipole character; the emission is caused by hyperfine structure perturbations occurring only in energy levels of the odd isotopes of mercury.

[1] S. Goudsmit and R. F. Bacher, Phys. Rev. **43**, 894 (1933).

22. Fine Structure and Series Extension in the Alkali Metal Atomic Spectra. H. R. KRATZ, *University of Wisconsin and Princeton University.*—The tube already described[1] for the production of a long optical path in a short space has been improved by supporting the optical parts on an I beam, with the aid of sylphon tubes, for stability with changing temperature, and by the installation of facilities for uniform heating to any temperature up to 500°C, controllable to about 0.1°C. Twelve members of the principal series of potassium have been resolved into doublets, and 75 members have been measured. Similar work is progressing upon rubidium and caesium.

[1] H. R. Kratz and J. E. Mack, Phys. Rev. **57**, 1059A (1940).

23. Bands in the Vapors of the Alkali Metal Atoms, in a Long Absorption Path. J. E. MACK AND H. R. KRATZ, *University of Wisconsin and Princeton University.*—In connection with the work described in the previous paper, with optical paths of tens of meters, many bands have appeared.

24. Raman Spectrum of Hexachloroethane. FORREST F. CLEVELAND, DWIGHT T. HAMILTON, AND M. J. MURRAY, *Illinois Institute of Technology.*—Beginning a study of some ethane type molecules, the Raman spectrum of Cl_3C-CCl_3 dissolved in carbon tetrachloride and chloroform has been obtained. The Raman data for hexachloroethane in the order *displacement* (*intensity*) *depolarization factor* are: 162(½)0.7; ±223(6)0.8; ±340(5)0.8; ±431(8)0.3; 859(5)0.9, and 975(2)0.4. (± means observed as both Stokes and anti-Stokes lines.) Previous data obtained for hexachloroethane in the order {*number of times line was observed*} *mean displacement* (*mean intensity*) *depolarization data* are: {3} 144(1)*r*; {9} 220(4)*v*; {12} 340(4)*v*; {12} 432(7)*r*; {1} 673(0); {9} 858(3)*v*; {3} 978(1)—. (*r*, *v* = right

and left circularly polarized.) Since the Cl atoms are large enough to exert considerable forces upon each other, it seems reasonable to suppose that rotation of one CCl_3 group with respect to the other about the C−C bond is restricted by a high potential barrier and that the equilibrium configuration is one in which the CCl_3 groups have their symmetry planes displaced by $\pi/3$. This configuration, D_{3d}, should yield, in agreement with the above observations, three polarized and three depolarized Raman lines, as contrasted with three polarized and six depolarized Raman lines for either the D_{3h} or the D'_{3h} configurations.

25. Analysis of the Near Ultraviolet Absorption Spectrum of Phenol. MAURICE B. HALL,* *Duke University.*—Near ultraviolet absorption spectrograms of phenol, obtained with a Hilger E-1 quartz spectrograph, were studied. To a good approximation the spectrum was found to conform to the requirements of the C_{2v} symmetry class, being very similar to the spectra of the monohalogenated benzenes. The 0, 0 band ($A_1 \rightarrow B_1$ transition) occurs at 36351 cm^{-1}. Progressions with spacings of 782 cm^{-1} and 935 cm^{-1}, and intercombinations of the two, were found arising from totally symmetric vibrations. The difference 478 cm^{-1}, occurring alone and in combination with some totally symmetric levels, was assigned to a β_1 vibration. This vibration is considered to correspond to the ϵ^+_g vibration in benzene whose excitation is responsible for the near ultraviolet benzene absorption. Bands displaced from the main bands by about 60 cm^{-1} and 218 cm^{-1} towards longer wave-lengths are explained as $v-v$ transitions. A small influence of the hydrogen atom of the OH group is suggested in some minor features.

* Now at National Institute of Health, Bethesda, Maryland.

26. On the Theory of the "Color" of Unsaturated Aliphatic Chains. U. FANO, *Carnegie Institution of Washington.*—The spectral absorption bands of aliphatic molecular groups having increasing numbers of conjugated double bonds (up to 11) are progressively shifted towards red. The shift is, however, much slower than theoretically expected according to Bloch's approximation. Since this approximation is particularly inaccurate in one-dimensional systems, other qualitative considerations are presented here. In Heitler-London's approximation, the fundamental state is entirely non-ionic, but the lowest optically excited state includes only ionic configurations. The smallest optically absorbed frequency is then primarily determined by the energy difference between non-ionic and ionic configurations, which is a zero-order effect, rather than by the strength or number of bonds. (The matrix elements interconnecting ionic and non-ionic configurations are assumed here to be small, but when the chain is sufficiently long their large number upsets Heitler-London's approximation.) Thus no major shift of the absorption bands would be expected for chains of moderate length, if the energy difference between ionic and non-ionic configurations (neglected in Bloch's approximation) were the dominant factor. As things are, this factor is probably strong enough to oppose appreciably the shift towards red, thus explaining the experimental findings.

27. Influence of *l*-Quantum Number on the Structure of X-Ray Absorption Edges. R. SMOLUCHOWSKI, *General Electric Company.*—The transition probability of an electron in absorption of an x-ray quantum depends upon the wave function of the lower state. Most of the studies of the fine structure of x-ray absorption edges consider only the K edge and do not reveal this dependence. Besides, for solids, almost no quantitative theoretical considerations are possible. In case of molecular gases, however, Kronig's theory can be extended to other edges and quantitative predictions made. Experimental study of the fine structure of the L_I, L_{II}, and L_{III} absorption edges of mercury in gaseous $HgCl_2$ were made in order to study the influence of the orbital quantum number on the structure. The results indicate that the L_I edge has a structure different from that of the L_{II} and L_{III} edges at least within the observed range of energies. The L_{II} and L_{III} edges have identical structures as expected. Theoretical results for L_I are in good agreement with experiment. A quantitative comparison of the structure of the other two edges with the extended theory has not yet been carried out.

28. Electron Polarization. C. G. SHULL,* *New York University.*—In treating the scattering of electrons by atomic nuclei, Mott[1] has shown that the interaction of the electron's magnetic moment with the scattering nucleus is such as to cause an intensity asymmetry upon the double scattering of a beam of electrons. Experimental observation of this effect is a crucial test of the validity of the Dirac equations for electrons. This experiment has been repeated using a 400 kev beam of electrons scattered by thin gold foils and counted by Geiger-Müller counters. After eliminating spurious asymmetries, a polarization asymmetry of 8 percent was found, which became 1 percent in the opposite direction when an aluminum foil was inserted for one of the gold foils. Reducing the atomic number of the scattering centers in this way should theoretically reduce the polarization asymmetry to a much smaller value. A distinction has been determined between polarization asymmetries as obtained in a "reflection" experiment (in which only electrons scattered through the "reflecting" sides of the foils are studied) and in a transmission experiment (in which only electrons scattered through the transmitting sides are studied). Experimental data will be shown and analyzed.

* Now with The Texas Company, Beacon, New York.
[1] N. F. Mott, Proc. Roy. Soc. **135**, 429 (1932).

29. Abnormal Scattering of Electrons. PAUL E. SHEARIN, *University of North Carolina.*—Skobelzyn[1] reports that, in at least ten percent of the cases, the angle of scattering of a primary electron, in an electron-electron collision, is much greater than that to be expected from energy and momentum considerations. For expected angles of scattering of about 4°, he reports angles as great as 40°. A stereoscopic visual examination of the 180 side-branches of energy superior to 20 Kev occurring on 343 meters of primary

electron track of energy between 1.3 and 2.6 Mev, studied in a recent investigation by Pardue[2] and the author, disclosed no marked abnormal scattering. Ninety-one of these events were suitable for accurate angular measurements, and were utilized in the present work. The angle of deflection of the primary in a plane approximately parallel to the primary track was measured. In only one case was the measured angle appreciably greater than the calculated angle, and this discrepancy could be accounted for by a nuclear collision near the electron-electron collision.

[1] Skobelzyn, Comptes rendus **21**, 431 (1938).
[2] Shearin and Pardue, Proc. Am. Phil. Soc. **85**, 243 (1942).

30. Secondary Emission of Electrons from Molybdenum Plates Coated with Beryllium and Treated with HCl. PAUL L. COPELAND AND WILLIAM R. KENNEDY, *Illinois Institute of Technology.*—Molybdenum plates used in these experiments were placed in vacuum and outgassed. Beryllium was then evaporated to form thick films upon them. The plates, after being removed from the vacuum system, were washed first with concentrated hydrochloric acid and then with distilled water to remove all visible traces of the beryllium film. After such plates had been placed in experimental tubes for the measurement of secondary emission and outgassed at a bright red heat, they showed relatively high secondary emission over a wide range of primary energies. A maximum of something more than three secondaries per primary appeared at a primary energy of about 500 electron volts.

31. Proton Production by Electron Collisions in Molecular Hydrogen. HERBERT F. NEWHALL, *Cornell University.*—The collision processes leading to the production of protons by single electron collisions with molecular hydrogen were investigated, using a mass spectrometer for the analysis. The electron beam was coaxial with a cylindrical conductor, and the field due to the electron space charge was used as an energy selector for the ions. The ions measured were those moving initially at right angles to the beam. The "fast" protons (ions having several electron volts of energy) found by Bleakney[1] were observed, and a rough measurement of the cross section for their production was made. No evidence was found for the slow protons observed by Bleakney. It is believed that these were formed by secondary collision processes. Using the theory developed by Smith,[2] it is possible to compute roughly the energy distributions of the ions. The distributions are in accord with the potential energy curves of the hydrogen molecule.

[1] W. Bleakney, Phys. Rev. **35**, 1180 (1930).
[2] L. P. Smith and P. L. Hartman, J. App. Phys. **11**, 220 (1940).

32. The Polarization Parameters of Several Solid Dielectrics and Their Changes with Temperature and Composition. ROBERT F. FIELD, *General Radio Company.*—According to K. S. and R. H. Cole the changes in dielectric constant and loss factor with frequency for a single polarization in any dielectric are such that a plot of loss factor against dielectric constant is a circular arc with its center depressed below the dielectric constant axis. Three parameters are sufficient for specifying the polarization: the change in dielectric constant from zero to infinite frequency, the relaxation frequency, and the storage coefficient which is related to the depression angle. Important derived quantities are the zero frequency and infinite frequency dielectric constants and the maximum loss factor. Values of these six parameters have been calculated for several dielectrics from published data which cover a wide temperature range. The temperature coefficients of zero frequency dielectric constant, change in dielectric constant, and storage coefficient are negative. Relaxation frequency is an increasing exponential function of temperature.

33. The Effect of High Electrostatic Fields upon the Vaporization and Resistance of Molybdenum Filaments. WALTER P. REID, *University of Pittsburgh.*—In 1921 Worthing observed decreases in the vaporization rates and resistances of W filaments upon application of sufficiently high electrostatic fields directed radially outward. The filaments returned to normal upon removing the fields. Later Gaylord Estabrook investigated the phenomena in greater detail using Mo filaments. Vaporization rates as small as 1 percent of that without a field were obtained. He found increases in resistance however upon application of the fields. Lloyd Jones working more recently with a very good vacuum did not observe either effect. A careful study of the results obtained by Estabrook reveals that the phenomena mentioned, as well as other factors involved, can be explained by postulating that an adsorbed layer of oxygen forms on the filament surface upon application of a field, and leaves upon its withdrawal. Equations based upon such an assumption are found to fit Estabrook's observed variation of vaporization rate with field strength. The sudden change in resistance is attributed to a temperature change resulting primarily from a small change in emissivity.

34. The Effect of High Electrostatic Fields on the Conductivity of Tungsten. PETER L. VISSAT, *University of Pittsburgh.*—A grounded tungsten wire (0.0078-mm diameter) was mounted coaxially to a cylinder made negative relative to the wire and a difference of potential was applied between cylinder and wire. The procedure consisted of measuring the resistance of a tungsten wire first without an electric field and then with a field. With a vacuum of about 10^{-6} mm Hg and with fields of about 10^{6} volts/cm, measurements showed that: (1) An increase in resistance always resulted with the application of the field. (2) The change was different for different temperatures of the filament and for different vacuum conditions. (3) No measurable change occurred unless the field exceeded a certain value. (4) A small leakage or ionization current was associated with the changes in resistance. The observed changes might have been caused by: (1) leakage current, (2) ionization current, (3) radial stress in the wire resulting from the high field, or (4) other reasons. Calculations showed that reasons (1) and (3) produce changes much smaller than those observed and that the results are explainable wholly by reason (2) if it is assumed that most of the ionization occurs near the surface of the wire.

35. The Mechanism of the Electric Spark. JOHN ZELENY, *Yale University.*—A criticism is given of Meek's derivation of a formula for the radial field arising from the positive ions in an electron avalanche. The importance ascribed by Loeb and Meek to this radial field in the development of a spark discharge is questioned because values of sparking potentials in equal agreement with experiment can be obtained on the simple assumption that a spark will pass when the number of electrons liberated in an avalanche is 10^9. This assumption also leads to sparking potentials in a gas at different pressures which are in agreement with Paschen's law. The significance of the necessity of the production of a large number of electrons is ascribed to the photo-ionization that accompanies ionization by electron impact. This photo-ionization must reach a certain magnitude before it can definitely give rise to a conducting path between the two electrodes. The probability that such a path will be produced by a given amount of photo-ionization may well depend on the path length, and this may account for the fact that the values of sparking potentials computed by the formula on the assumption of a constant number of electrons fall more and more below the observed values as the distance between the electrodes is increased.

36. A Mass Spectrometer of Wide Adaptability. N. D. COGGESHALL, *University of Illinois.*—The simultaneous fulfillment of the conditions for: high sensitivity; high dispersion; comparative freedom from space charge effects; simplicity of operation; and inexpensive construction have been attained in an instrument for the measurement of relative abundances. Important features of the design are (1) the elimination of non-uniform and distorted magnetic fields in the source region as previously used in the 60° type of spectrometer, and (2) simplicity of construction and alignment. The ions are created in a magnetic field free region in which the electron beam moves perpendicular rather than parallel to the first slit. They are then accelerated towards this slit by an electrical field which remains fixed throughout a run. The final energy of the ions after passing through a second accelerating field is approximately 1000 volts. The ion source is constructed as a unit in such a way that an accurate alignment of the slits is readily accomplished and different source arrangements may be used. After leaving the source, the ions are deflected through a mean angle of $\pi/3$ radians by a uniform sector shaped magnetic field into a Faraday cup. The corresponding ion beam currents are measured directly by means of the usual electrometer tube arrangement.

37. Mobility of He^+ in He. ROLAND MEYEROTT, *Yale University.* (*Introduced by H. Margenau.*)—Tyndall and Powell have concluded from their measurements[1] that the mobility of He^+ in He is 21.4, a value which is in flagrant disagreement with that calculated by Massey and Mohr (12).[2] An improved calculation of the force law does not remove this discrepancy, while on the other hand the experimental value has been confirmed. An examination of the earlier work of Tyndall and Powell[3] reveals the value 13 for the mobility. The two determinations differ only in the nature of the ion sources used. It is suggested, from consideration of these ion sources, that the value 21.4 refers not to the mobility of He^+ in He but to that of the molecule-ion He_2^+ in atomic helium, and that the value 13 be taken as the mobility of He^+ in He. Evidence for these conclusions will be presented.

[1] Tyndall and Powell, Proc. Roy. Soc. **134**, 125 (1931).
[2] Massey and Mohr, Proc. Roy. Soc. **144**, 188 (1934).
[3] Tyndall and Powell, Proc. Roy. Soc. **129**, 162 (1930).

38. Electronically Controlled Variable Capacity. L. GRANT HECTOR, GORDON GUERNSEY AND CHESTER MARCINKOWSKI, *University of Buffalo.*—Variable capacity condensers are ordinarily obtained by the simple expedient of arranging one set of plates of a multiplate condenser to be moved either by hand or by a motor. The effective amount of capacitative reactance in a circuit may also be varied by placing a fixed condenser in the circuit with a variable series resistance included. If the variable series resistance consists of the plate circuit of a thermionic tube, variable capacitative reactance may be obtained without the use of mechanical moving parts. Both the type and the extent, as well as the rate of the variations can be controlled by the signal imposed on the grid of the tube. One application of the device is to produce warble tones for acoustical measurements. An obvious current application of this method for producing warble tones of various types is in combination with sirens as air raid warning signals.

39. A Magnetic Study of the Superconducting Transitions of Hydrides and Nitrides of Columbium and Tantalum. F. HUBBARD HORN, W. F. BRUCKSCH. JR., W. T. ZIEGLER AND D. H. ANDREWS, *The Johns Hopkins University.*—Measurements of magnetic induction were carried out in a duplex cryostat similar in design to the one reported by Simon in which liquid helium was produced by the expansion method in an upper vessel and the cooling effect transferred by refluxing to the lower vessel in which the samples were placed. Results may be summarized as follows where the composition is given in atom percent, the temperature in °K refers to the midpoint of the transition and the figures in parentheses give the approximate width of the transition: Columbium, pure metal, 8.98°K (0.4°); 5.06 percent H, 7.83° (2.1°); 9.89 percent H, 7.38° (3.2°); 32.76 percent H, 7.28° (3.2°). Tantalum, pure metal, 4.08°K (0.2°); 3.97 percent H, 3.62° (0.8°); 7.54 percent H, 3.26° (1.2°); 11.93 percent H, 2.81° (1.8°). At the lowest temperature obtained, 2°K, tantalum nitride failed to become superconducting. In columbium nitride (CbN) superconductivity first appeared at about 14.5°K and the substance passed through a transition 1.3° in width as the temperature was lowered. A direct electrical measurement of the resistance on a sample of compressed powder showed a drop in resistance from about 10 ohms in the normal state to 0.4 ohm when superconducting.

40. On the Adiabatic Demagnetization of Iron Alum. J. A. SAUER,* *Harvard University.*—Experiments performed by Casimir and De Haas[1] on the adiabatic demagnetization of iron alum from high initial fields have determined the

relationship between the magnetic moment and the field strength. The proper qualitative form of this relationship was derived from theoretical considerations by the same authors but only for the case of low values of the initial magnetizing field. For high values no theoretical solution was available. This is now obtained by using a method of attack originally developed by Van Vleck but extending it to include the effect of the crystalline field that, together with the magnetic dipole-dipole interaction, hinders the free orientation of the paramagnetic ions. The theoretical expression for the variation of the adiabatic magnetic moment with the magnetic field strength is found to compare favorably, quantitatively as well as qualitatively, with that determined by experiment. It is also shown that if the true thermodynamic temperature be determined by the method of De Haas and Wiersma—T proportional to H—the error involved is negligible over a suitable temperature range.

* Now at Mellon Institute, University of Pittsburgh.
[1] H. B. G. Casimir and W. J. De Haas, Physica **7** (1940).

41. Crystal Planes Developed by d.c. Heating of Tantalum. D. B. LANGMUIR, *RCA Research Laboratories, Inc.**—The "etching" of metallic surfaces by action of steady voltage gradients[1] has been studied. Tantalum strips 0.001" thick and 1–5 mm wide often recrystallize with grain diameters over 1 mm when heated to about 2500°K. Heating to about 2100°K in vacuum with d.c. for several hours causes surfaces to become deeply ridged. Spacing between adjacent ridges is of order 0.01 mm. Opposite sides of the same crystal grains usually show radically different surface structures. A.c. heating develops no structure, surfaces remaining mirror smooth. Negligible evaporation occurs. Twelve crystal grains have been studied by both x-ray and optical observations. Laue back reflection patterns showed the orientation of the body-centered cubic axes. Using a simple optical goniometer, reflections from the macroscopic "etched" surfaces have been found to be sharp in some cases to 2° and in most to better than 5°. The combined observations give the Miller indices of the macroscopic surfaces developed by the d.c. heating. The prominent optical reflections (2 or 3 from an average crystal) come from surfaces coinciding mostly within 5° with low index atomic planes. (110), (211), and (100) surfaces have been found. Which particular set of surfaces develops depends upon the orientation of the crystal axes and upon the polarity of the current flow. Were optical measurements alone made, the false conclusion could be drawn that the crystal had a polar axis.

* Now employed by the Office of Scientific Research and Development, Washington, D. C.
[1] R. P. Johnson, Phys. Rev. **54**, 459 (1938).

42. The Crystal Structure of Tetraphenyl Arsonium Tri-Iodide. ROSE C. L. MOONEY, *Newcomb College, Tulane University.*—As part of a study of the effect of cation size upon the structure and properties of tri-iodide compounds in the solid state, the crystal structure of tetra-phenyl arsonium tri-iodide, $(C_6H_5)_4AsI_3$, has been determined by means of x-rays. The cation tetrahedron, previously measured in the iodide, has an edge of almost eight angstroms. Unlike the better known tri-iodides, the tetraphenyl arsonium salt is very stable and extremely insoluble. The diffraction data was obtained from very small single crystals by the equi-inclination Weissenberg technique. The structure was determined directly from x-ray data by Fourier methods. The crystal is monoclinic, and has the symmetry of $P2/n(C_{2h}^4)$. There are two molecules in a cell of dimensions, $a=15.31$A, $b=7.63$A, $c=10.61$A; angle $\beta=93.4°$. The density, from x-ray measurements, is 2.04 g/cc. The arsenics and one pair of iodines are, respectively, in rotation axes and symmetry centers. The remaining parameters, forty in number, have also been accurately determined, so that there is excellent agreement between observed and calculated structure amplitudes. The tetraphenyl arsonium ions are packed between layers of tri-iodide ions, with carbon-iodine coordination distances of 4.15A.

43. Dispersion of Sound at High Frequencies in Cylindrical Rods. GEORGE E. HUDSON, *Brown University.* (*Introduced by R. B. Lindsay.*)—The theory of elastic vibrations in solid circular cylindrical rods of homogeneous isotropic materials is redeveloped from the general equations of elasticity with the following general results: (1) for any mode of vibration the ratio of the velocity of any elastic wave travelling along the rod to the velocity c_0 of shear waves is the same for any two rods whose Poisson ratios are equal and whose ratios of circumference to shear wave-length are equal, (2) if the velocity of propagation for any particular mode remains less than c_0 as the frequency or radius is increased indefinitely, this velocity approaches that of Rayleigh surface-waves, (3) a considerable simplification is introduced into the method of computing dispersion curves for any mode. This investigation generalizes and extends the work of Bancroft,[1] on elongational waves, and, further, a table of dispersion curves for the flexural mode of vibration is computed. The dispersion curves for magnesium are compared with the experimental results of Shear and Focke.[2] Excellent agreement between theory and experiment is obtained for the first elongational and flexural branches.

[1] Bancroft, Phys. Rev. **59**, 588–593 (1941).
[2] Shear and Focke, Phys. Rev. **57**, 532–537 (1940).

44. An Experimental Study of the Vibrations of Incomplete "Free-free" Circular Rings. F. P. BUNDY AND CLYDE W. BANKES, *Ohio University.*—The rings used in this investigation had air gaps of nearly 4° between the free ends. The first five modes of vibration in the plane of the ring and the first four modes of vibration transverse to the plane of the ring were successfully produced. In each case the frequency and the "form" of the vibration were determined as accurately as possible. It was found that the frequency of vibration in the plane of the ring is given accurately by the expression,

$$f_n=(K_n/D^2)(EI/m)^{\frac{1}{2}},$$

where n is the mode of vibration, D the mean diameter of the ring, EI the bending stiffness in the plane of the ring, m the mass per unit length, and K_n a constant which de-

pends upon n. The frequencies for vibrations transverse to the plane of the ring are given by a similar expression in which the "constant" K depends upon n and the ratio of bending stiffness to torsional stiffness.

45. Use of the Pierce Interferometer for Measuring the Absorption of Sound in Gases.* HOWARD C. HARDY, *University of New Hampshire.*—An empirical equation has been used by Pielemeier to measure the absorption of sound in gases at high frequencies. It gives the energy absorption coefficient per wave-length, μ, as

$$\mu = \frac{2.303}{N_B - N_A} \log_{10} \frac{\Delta I_A}{\Delta I_B},$$

where

ΔI_A, ΔI_B = differences between the plate current at resonance and anti-resonance, the reflector being at positions A, B.

$N_B - N_A$ = the number of whole wave-lengths between A and B.

This equation is here derived from theoretical considerations of the principles of the Pierce interferometer and the quartz oscillator and is found to be an excellent approximation when certain conditions as to reflector position and sound energy are fulfilled. The criteria for accurate measurement at high frequency of absorption coefficients are set up and experimental verification is shown. A more complete explanation of the effect of sound resonance on the quartz oscillator is given also.

* This research was carried out at the Pennsylvania State College. State College, Pennsylvania.

46. The Translational Dispersion of Sound in Gases. H. PRIMAKOFF, *Queens College.*—The translational dispersion of sound in gases is discussed from the standpoint of kinetic theory. The distribution function for molecular velocities in a gas carrying a sound wave is used to determine the space and time dependence of the gas pressure, density, and mean molecular velocity. Thus, an explicit relation is derived for the variation of the sound velocity V, with frequency; in monatomic gases this relation is: $V = V_0(1 - 5.4l^2/\lambda^2)$, where l is the molecular mean free path and λ is the wave-length. The possibility of experimental observation of translational dispersion is briefly discussed.

47. The Coefficient of Thermal Diffusion of Argon and Its Variation with Temperature. L. G. STIER, *University of Minnesota.*—Nier has measured the coefficients of thermal diffusion of methane[1] and neon[2] and in both cases observed a definite temperature dependence. Using the 9,5 Lennard-Jones[3] model of intermolecular forces with appropriate modifications, Jones obtained quantitative agreement with Nier's experimental results. The same theory also predicts that R_T is negative for temperatures less than $1.54T_c$, where R_T is the ratio of α to the value computed for hard spheres and T_c is the critical temperature. For argon the coefficient would be negative in the range 90° to 195°K. The coefficient of thermal diffusion of argon has been measured over seven different temperature intervals from 90°K to 833°K. In all cases α was positive. The results show that within experimental error α varies linearly with $\ln T$ if T is the "average" temperature over the range as calculated from Sutherland's model.[4] The R_T's fall between those of neon[2] and methane[1] for corresponding temperature ranges and agree with those computed from measurements of binary mixtures of the rare gases.[5]

[1] A. O. Nier, Phys. Rev. **56**, 1009 (1939).
[2] A. O. Nier, Phys. Rev. **57**, 338 (1940).
[3] R. C. Jones, Phys. Rev. **59**, 1019 (1941).
[4] Harrison Brown, Phys. Rev. **58**, 661L (1940).
[5] B. E. Atkins, R. E. Bastick, and T. L. Ibbs, Proc. Roy. Soc. **A172**, 142 (1939).

48. Effect of Double Layer on the Forces Between Neutral Molecules and Metal Surfaces. W. G. POLLARD, *University of Tennessee.*—Consideration is given to the question whether the existence of a double layer, such as that considered by Smoluchowski[1] in connection with the electronic work function, will profoundly modify the van der Waals force[2] between a metal surface and a neutral atom. It is found that the "spreading" effect[1] increases the coefficient of the van der Waals force without changing its (asymptotic) dependence on distance of separation; the relative change in the energy is given by $\Delta W/W \approx 20(p/e)r_s$, p being dipole moment per unit area of the surface layer, r_s the radius of the s sphere. For sodium this change amounts to only about 7 percent, but for tungsten it may increase the energy by as much as 50 percent. The difference between the various faces is small. An investigation of the "smoothing" effect shows it to produce a dependence of forces on distance differing from the R^{-4}-law; in fact the energy decreases exponentially. While it modifies strongly the forces near the surface and is therefore important in a complete consideration of the adsorption problem, it does not change the asymptotic form of the interaction.

[1] R. Smoluchowski, Phys. Rev. **60**, 661 (1941).
[2] H. Margenau and W. G. Pollard, Phys. Rev. **60**, 128 (1941).

Author Index to Abstracts of Contributed Papers Presented at the Baltimore Meeting

Andrews, D. H.—see Horn, F. Hubbard

Banet, Leo—No. 10
Bankes, Clyde W.—see Bundy, F. P.
Bergmann, Peter G.—No. 1
Brucksch, W. F., Jr.—see Horn, F. Hubbard
Bundy, F. P. and Clyde W. Bankes—No. 44

Cleveland, Forrest F., Dwight T. Hamilton, and M. J. Murray—No. 24
Coggeshall, N. D.—No. 36
Copeland, Paul L. and William R. Kennedy—No. 30

Dresden, M.—No. 8

Ehrenhaft, Felix—No. 9

Fano, U.—No. 26
Field, Robert F.—No. 32
Froman, Darol K.—see Rossi, Bruno

Greisen, Kenneth—see Rossi, Bruno
Greuling, E.—No. 5
Guernsey, Gordon—see Hector, L. Grant

Hall, Maurice B.—No. 25
Hamilton, Dwight T.—see Cleveland, Forrest F.
Hardy, Howard C.—No. 45
Hector, L. Grant, Gordon Guernsey, and Chester Marcinkowski—No. 38
Horn, F. Hubbard, W. F. Brucksch, Jr., W. T. Ziegler, and D. H. Andrews—No. 39
Hudson, George E.—No. 43

Kennedy, William R.—see Copeland, Paul L.
Klaiber, Stanley and Gertrud Scharff-Goldhaber—No. 12
Koontz, Phillip G.—see Rossi, Bruno
Kratz, H. R.—No. 22
—— see Mack, J. E.
Kurbatov, J. D.—see Nelson, Martin E.

Langmuir, D. B.—No. 41

Mack, J. E. and H. R. Kratz—No. 23
Marcinkowski, Chester—see Hector, L. Grant
Meyerott, Roland—No. 37
Miller, Carlton W. and C. G. Montgomery—No. 15
Montgomery, C. G.—see Miller, Carlton W.
Mooney, Rose C. L.—No. 42
Mrozowski, S.—No. 21
Murray, M. J.—see Cleveland, Forrest F.

Nelson, Martin E., M. L. Pool, and J. D. Kurbatov—No. 11
Newhall, Herbert F.—No. 31
Nordheim, L. W.—see Richards, J. A., Jr.

Pollard, W. G.—No. 48
Pool, M. L.—see Nelson, Martin E.
Primakoff, H.—No. 46

Regener, Victor H.—No. 16
Reid, Walter P.—No. 33
Richards, J. A., Jr. and L. W. Nordheim—No. 18
Roberg, Jane—No. 19
Rossi, Bruno, Kenneth Greisen, Joyce C. Stearns, Darol K. Froman, and Phillipp G. Koontz—No. 17

Sachs, R. G. and Julian Schwinger—No. 7
Sauer, J. A.—No. 40
Scharff-Goldhaber, Gertrud—see Klaiber, Stanley
Schwinger, Julian—see Sachs, R. G.
Shearin, Paul E.—No. 29
Sherr, R.—No. 13
Shull, C. G.—No. 28
Slepian, J.—No. 4
Smoluchowski, R.—No. 27
Stearns, Joyce C.—see Rossi, Bruno
Stier, L. G.—No. 47
Swann, W. F. G.—No. 14

Tisza, L.—No. 2

Vissat, Peter L.—No. 34

Warburton, F. W.—No. 3
Welles, S. B.—No. 6
Wood, R. W.—No. 20

Zeleny, John—No. 35
Ziegler, W. T.—see Horn, F. Hubbard

Author Index to Volume 61

References with (A) are to abstracts of papers presented at meetings of the American Physical Society.
References with (L) are to Letters to the Editor and those with (T) designate title only.

Albers, V. M. (see Fry, David)—729(T), 730(A)
—— (see Knorr, H. V.)—546(A)
—— (see Stewart, Albert)—729(T), 729(A)
—— **and H. V. Knorr.** Problem of determining a standard for chlorophyll preparations—546(A)
Albertson, Walter E., George R. Harrison, and J. Rand McNally, Jr. First spark spectrum of neodymium—preliminary classification and Zeeman effect data—167
Allen, James S. Experimental evidence for the existence of a neutrino—692
Almy, G. M. and A. C. Beiler. Potential energy curve of the excited state of KH—476
Altmann, George O. (see Benedetto, F. A.)—266
—— (see Hess, Victor F.)—393(A)
Amberg, C. R. Application of polarized light and x-rays to the ceramic industry—101(T)
Anderson, E. W. (see Bosch, W. C.)—726(A)
Anderson, Thomas F. (see Richards, A. Glenn, Jr.)—383(T)
Andrews, D. H. (see Horn, F. Hubbard)—738(A)
Angello, S. J. Hall effect in cuprous oxide—391(A)
Anslow, Gladys A. Bond energies in COOH and COHN dimers, indicated by ultraviolet absorption bands—546(A)
—— Bond energies in some protein fabrics and side chains—547(A)
—— Teaching and research programs of the Department of Physics at Smith College—98(T)
Anthony, R. L. (see Caston, R. H.)—542(A)
Auger, Pierre V. Nature of the soft component of cosmic rays at 3500 meters altitude—684
—— **and Jean Daudin.** Absorption of extensive atmospheric showers of cosmic rays in air and lead—91
—— **and Jean Daudin.** Diurnal variation of extensive showers—95(L)
—— **and Jean Daudin.** Multiple secondary effects of the penetrating cosmic radiation at sea level—549
Austen, A. E. W. and S. Whitehead. Electric strength of dielectrics—199(L)
Avrami, Melvin and J. B. Little. Diffusion of heat through a rectangular bar and the cooling effect of fins. I. The steady state—392(A)
—— **and Victor Paschkis.** Application of an electric model to the study of two-dimensional heat flow—394(A)

Bailey, Carl L. and John H. Williams. Thick-target yield of Na^{24} under deuteron bombardment—539(L)
Baker, Richard F. (see Hillier, James)—722(L)
Bale, William F. Some recent developments in radiology—101(T)
Ballard, Stanley S. and Carroll B. Mills. Spectrographic determination of traces of potassium in sodium—108(A)
Band, W. Comparison spaces—702
——Is space-time flat?—698
Banet, Leo. Magnetic current in liquids—733(A)
Bankes, Clyde W. (see Bundy, F. P.)—739(A)
Banks, Floyd R. (see Miller, P. H., Jr.)—648
Barker, E. F. (see Posey, L. R.)—546(A)
Barnes, B. T. Radiation of mercury vapor—98(T)
Barnes, LeRoy L. Radioactive tracers in biological research—725(T)
Barr, E. S. and L. B. Scott. Method of preparing gray scales—728(A)
Barschall, H. H. and Rudolf Ladenburg. Elastic and inelastic scattering of fast neutrons—129
Bartlett, Russell S. Adapt the instruction to the student—100(T)
Bassett, Leon. Spectroscopy in ceramics—101(T)
Beam, R. E. M.k.s. system, its justification and use—384(T)
Bearden, J. A. (see Beeman, W. W.)—455
Beck, C. A. and H. Sponer. Near ultraviolet absorption spectrum of monodeuterobenzene—386(A)
Beck, G. and San-Tsiang Tsien. Nuclear levels of the compound Li_5—379(L)
Beeman, W. W. and J. A. Bearden. *K*-absorption edges of metal ions in aqueous solution—455
Beiler, A. C. (see Almy, G. M.)—476
Benedetto, F. A., G. O. Altmann, and V. F. Hess. Mesotron studies with dual telescope—266
Bennett, Albert A. Relation of mathematics training to physics training—724(T)
Bennett, Willard H. Angular distribution of current from a point in hydrogen—53
Bergmann, Peter G. Covariant representation of five-dimensional field theories—731(A)
Beringer, Robert and C. G. Montgomery. Angular distribution of positron annihilation radiation—222
Berry, Edward B., S.J. Cosmic-ray measurements between New York and Valparaiso—394(A)
Berry, H. W. Ionization by neutral atoms in the 2000- to 8000-ev energy range—392(A)
——, **R. N. Varney, and S. Newberry.** Ionization of gases by collisions of their own accelerated atoms and molecules—63
Bessey, R. J. On the theory of the internal conversion of gamma-radiation—544(A)
—— (see Uhlenbeck, G. E.)—544(A)
Bethe, H. A. (see Blanch, G.)—543(A)
Beutler, H. and M. Fred. Intensity anomalies by collisions in perturbed rotational bands—107(A)
Birge, Raymond T. Value of the electronic charge—206(A)
—— Value of the Faraday—204(A)
Blake, F. C. Extension of space group theory to submicroscopically twinned crystals and its application to certain spinels—108(A)
—— Further order-disorder studies in the case of certain spinels—729(T), 729(A)

Blanch, G., A. N. Lowan, R. E. Marshak, and H. A. Bethe. Internal temperature-density distribution of Sirius A—543(A)
Bleuler, E., P. Scherrer, and W. Zunti. Single scattering of fast electrons—95(L)
Bloch, F. and M. Hamermesh. Further results on magnetic scattering of neutrons—203(A)
Bohm, D. J. and Roy Thomas. High energy scattering of deuterons by protons—203(A)
Born, M. On the theory of temperature diffuse scattering—377
Borst, Lyle B. Deuteron-tritium reaction in nitrogen and fluorine—106(A)
Bosch, W. C. and E. W. Anderson. Ultraviolet absorption spectra of some sugars—726(A)
Bostick, W. H. Cloud-chamber photographs at 4310 meters altitude—104(A), 557
Boyce, Joseph C. Opportunities for the college physics department in the present war—724(T)
Boyd, G. E. (see Harkins, William D.)—104(A)
Boyd, Robert A. and Ralph A. Sawyer. Hyperfine structure of Cs II—601
Braun, Milton L. Neoprene under periodic stress—728(A)
Brillouin, Leon. Theory of the magnetron—103(A)
Brown, S. Leroy. Applications of the multiharmonograph to the graphical solution of physical and mathematical equations—205(A)
—— (see Wheeler, Lisle L.)—383(A)
Broxon, James W. Solar influence on cosmic-ray intensity—545(A)
Brucksch, W. F., Jr. (see Horn, F. Hubbard)—738(A)
Buck, Thomas. Some observations on a dynamic coulometer—729(T)
Bueso-Sanllehí, F. (see Mrozowski, S.)—108(A)
Bundy, F. P. and Clyde W. Bankes. Experimental study of the vibrations of incomplete "free-free" circular rings—739(A)
Burke, Catherine L. Dielectric absorption in cellulose nitrate and in methyl methacrylate—100(A)

Carne, Gerald G. (see Copeland, Paul L.)—103(A), 635
Carr, H. E. Thermal diffusion tube for liquids—726(A)
Caston, R. H., R. L. Anthony, and E. Guth. Equations of state for stressed rubber—542(A)
Christy, R. F. and J. M. Keller. Precise determination of the fine structure constant from x-ray spin doublet splitting—147
Clark, Arnold F. Radiations from radioactive gold, tungsten, and dysprosium—203(A), 242
Clark, K. C. and O. Oldenberg. Absorption spectrum as a quantitative test for mercury vapor in air—100(A)
Clarke, E. T. (see Korff, S. A.)—422
Cleveland, Forrest F. (see Saunders, Robert H.)—106(A)
—— (see Tauffen, H. J.)—106(A)
—— **and M. J. Murray.** Resonance interaction in the 2200 cm^{-1} region in the Raman spectra of acetylenes—106(A)
——, **Dwight T. Hamilton, and M. J. Murray.** Raman spectrum of hexachloroethane—735(A)
——, **M. J. Murray, and Robert H. Saunders.** Association effects in the Raman spectra of thiophenol solutions—386(A)
Clewell, D. H. Gravimeter—383(T)
Coggeshall, N. D. Mass spectrometer of wide adaptability—738(A)
Cole, Kenneth S. Nerve fiber impedance—391(A)
Coon, Jesse B. Rotational structure of some bands of chlorine dioxide—107(A)
Cooper, Eugene P. On the separation of nuclear isomers—1
Cooper, John N. Auger effect in relative intensities and widths of x-ray lines—234
Copeland, L. E. (see Harkins, William D.)—104(A)
Copeland, Paul L. and Gerald G. Carne. Excitation of the anode effect—103(A), 635
—— **and William R. Kennedy.** Secondary emission of electrons from molybdenum plates coated with beryllium and treated with HCl—737(A)
Cork, J. M. (see Kent, C. V.)—389(A)
——, **L. N. Hadley, Jr., and C. V. Kent.** On the relative probability of the D,2*n* and the D,*n* reactions in Ni and Zn—388(A)
Courant, Richard. Stability and instability demonstrated by soap film experiments—100(T)
Cox, R. T. Electric fish—673(T)
Crenshaw, C. M., V. J. Young, and H. P. Manning. Difference in loss of energy of deuterons in D_2 and H_2—388(A)
Creutz, Edward C. and Robert R. Wilson. Evidence for *p*-wave proton-proton scattering—388(A)
Critchfield, Charles L. On the theoretical half-lives of β-activities—249
—— Theoretical half-lives of beta-transitions—387(A)
Cullen, A. B. (see Kennon, W. L.)—728(A)

Dancoff, S. M. and W. Pauli. Strong coupling mesotron theory of nuclear interactions—387(A)
—— **and R. Serber.** Nuclear forces in the strong coupling theory—394(A)
Daniel, J. H. Field emission from tungsten and thoriated tungsten single crystals—657
Darrow, K. K. Concept of entropy—673(T)
Dates, Henry. Lighting the classroom—98(T)
Daudin, Jean (see Auger, Pierre)—91, 95(L), 549
Davidson, Norman. Theory of absolute reaction rates and the conductivity of hydrocarbons at high field strengths—721(L)
Debeau, David E. Nature of reactions occurring in the production of the afterglow of active nitrogen and the effect of temperature on the phenomena—668
Delaup, Paul S. and Quintin Holdeman. Photographic effect of zinc—726(A)
Dennison, D. M. (see Foley, H. M.)—386(A)
Deutsch, M. Absence of high energy beta-rays from Br^{82}—672(L)
—— (see Downing, J. R.)—389(A), 686
—— (see Elliott, L. G.)—99(A)
DeWire, J. W., M. L. Pool, and J. D. Kurbatov. Radioactive isotopes of praseodymium—544(A), 564
——, **A. Roberts, and L. G. Elliott.** Gamma-rays from long period activities—389(A)
Dighton, A. L. and H. A. Miley. Parabolic and logarithmic oxidation of copper—384(A)
Dodd, W. A. (see Lane, C. T.)—183, 391(A)

Downing, J. R., M. Deutsch, and A. Roberts. Disintegration schemes of radioactive substances. III. I^{131}—686
——, **M. Deutsch, and A. Roberts.** Study of the radiations from the disintegration of I^{130} and I^{131}—389(A)
Dresden, M. On the algebraic theory of higher spins—733(A)

Earle, Marshall D. Electrical conductivity of titanium dioxide—56
Ehrenhaft, Felix. Magnetic current in gases—733(A)
Eisenstein, A. and N. S. Gingrich. Comparison between a Geiger-Mueller counter, a secondary electron multiplier tube, and photographic film for detecting weak x-rays—104(A)
Elliott, D. S. and L. B. Scott. Improved procedure used in the measurement and analysis of some city noises in New Orleans—727(A)
Elliot, L. G. (see Deutsch, M.)—389(A)
——, **M. Deutsch, and A. Roberts.** Measurement of the energy of the gamma-radiation from Na^{24}—99(A)
Evans, Foster. Electric and magnetic effects of cosmic rays—680
—— New cosmic-ray geomagnetic relation—545(A)
Ewell, Arthur W. Ozone and ultraviolet light—724(A)

Fajans, Kasimir. Thermal expansion, compressibility, and electronic polarizability of ionic crystals—543(A)
Fan, H. Y. Theory of electrical contact between solids—365
Fano, U. On the theory of the "color" of unsaturated aliphatic chains—736(A)
Feenberg, Eugene. Theory of nuclear Coulomb energy—387(A)
Feeny, H., C. Lapointe, and F. Rasetti. Resonance absorption of neutrons in rhodium, antimony, and gold—469
Feshbach, H. Theory of hydrogen three—544(A)
Field, Robert F. Polarization parameters of several solid dielectrics and their changes with temperature and composition—724(T), 737(A)
Fiske, Milan D. Temperature scale, thermionics, and thermatomics of tantalum—513
Fitzsimmons, K. E. Threshold field studies of various positive corona phenomena—175
Foley, H. M. Self-broadening and foreign gas broadening in the infra-red absorption spectrum of HCN—545(A)
—— **and D. M. Dennison.** Pressure effects on spectral lines—386(A)
Forsythe, W. E. Establishing and maintaining a color temperature scale—729(T)
Fountain, C. R. Physics of driving an automobile—724(T)
Fred, M. (see Beutler, H.)—107(A)
Fröhlich, H. Electric breakdown of ionic crystals—200(L)
Froman, Darol K. (see Rossi, Bruno)—675, 734(A)
Fry, David, V. M. Albers, and H. V. Knorr. Absorption spectra in the visible of *ms*-tetra (3′, 4′-methylenedioxyphenyl) porphine of HCl No. 4 and three of its metal complex salts—730(A)
——, **V. M. Albers, and H. V. Knorr.** Absorption spectrum of *ms*-tetra-4-dimethylaminophenyl porphine—729(T)
Furry, W. H. Elementary explanation of thermal diffusion—388(A)

Gage, H. P. What the artists should know about the science of color—101(T)
Gage, O. A. Glass light filters—725(T)
Garten, William. Comparison of optical and electromechanical methods of studying ultrasonic fields—391(A)
Gehman, S. D. Rubber in vibration—542(A)
Gemant, Andrew. Field of electrets in the presence of gaseous ions—79
Gerjuoy, Edward and Julian Schwinger. On tensor forces and the theory of light nuclei—138
Germer, L. H. Electron diffraction studies on thin films. III. Powder patterns containing anomalies produced by secondary scattering—309
——, **F. E. Haworth, and J. J. Lander.** Order in the alloy Cu_3Au—93(L), 614
Gibbs, R. C. University defense training—725(T)
Gilvarry, J. J. (see Snyder, T. M.)—390(A)
Gingrich, N. S. (see Eisenstein, A.)—104(A)
Givens, M. P. Optical dispersion of copper and beryllium—626
Goeder, Frank P. (see Weber, Louis R.)—94
Gogate, D. V. and D. S. Kothari. Flow of energy in thermal transpiration for a Bose-Einstein and a Fermi-Dirac gas—349
Goodman, Clark and Dean C. Picton. Autoradiography of manganese ores—99(A)
Gorin, Everett. Theory of hydrocarbon reactions—383(T)
Grams, W. R. (see Johnson, R. P.)—671(L)
Green, Cecil H. Seismology—383(T)
Greene, J. B. and Millard F. Manning. Electronic energy bands in face-centered iron—542(A)
Gregory, Chris. Resonance broadening of caesium—465
Greisen, Kenneth I. Cosmic rays—725(T)
—— Intensities of the hard and soft components of cosmic rays as functions of altitude and zenith angle—212
—— (see Rossi, Bruno)—121, 675, 734(A)
Greuling, E. Theoretical half-lives of forbidden β-transitions—568
—— Theoretical half-lives of RaE and P^{32}—732(A)
Guernsey, Gordon (see Hector, L. Grant)—738(A)
Guth, Eugene (see Caston, R. H.)—542(A)
—— (see Mullin, Charles J.)—542(A)
—— **and Charles J. Mullin.** Electron emission of metals in electric fields. III. The transition from thermionic to cold emission—339

Hadley, L. N. (see Cork, J. M.)—388(A)
Hall, David B. Mesotron and electron energy spectrum at 14,260 feet altitude from absorption measurements in lead—105(A)
—— (see Schein, Marcel)—105(A)
Hall, Maurice B. Analysis of the near ultraviolet absorption spectrum of phenol—736(A)
—— (see Sponer, H.)—107(A)
Hamermesh, M. Magnetic scattering of neutrons—17
—— (see Bloch, F.)—203(A)
Hamilton, Dwight T. (see Cleveland, Forrest F.)—735(A)
Hamilton-Hall, Jane. Temperature diffuse scattering of x-rays by potassium chloride and potassium bromide crystals—158

—— (see Schein, Marcel)—105(A)
Handle, Niel. Static electric effects on rubber tired vehicles —541(T)
Hardy, Howard C. Use of the Pierce interferometer for measuring the absorption of sound in gases—740(A)
Hardy, T. C. and S. Millman. Radiofrequency spectrum of indium. Nuclear spin of In^{113}—459
Harkins, William D., L. E. Copeland, and G. E. Boyd. Two-dimensional phase of peculiar properties—104(A)
Harrison, George R. (see Albertson, Walter E.)—167
Haworth, R. E. (see Germer, L. H.)—93(L), 614
—— (see Manley, J. H.)—152
Hazen, Wayne E. Primary and probable ionization of helium by cosmic rays—202(A)
Heaps, C. W. Production of electric charges in water spray —384(T)
Hector, L. Grant, Gordon Guernsey, and Chester Marcinkowski. Electronically controlled variable capacity—738(A)
Heiland, C. A. Geophysical exploration and its part in national defense—383(T)
Heller, Wilfried and Germaine Quimfe. On the validity of the Langevin theory of orientation and the possibility of distinguishing between inherent and photoelastic anisotropy—382(L)
Helmholz, A. C. Gamma-rays from radioactive mercury—204(A)
Hess, V. F. (see Benedetto, F. A.)—266
—— **and George O. Altmann.** Effect of changes of height of air mass on mesotron intensity—393(A)
Hilberry, Ann Hepburn (see Hilberry, Norman)—393(A)
Hilberry, Norman. Extensive cosmic-ray shower experiments in the Peruvian Andes—100(T)
—— **and Ann Hepburn Hilberry.** Penetrating power of extensive cosmic-ray shower particles at sea levels—393(A)
Hillier, James (see Zworykin, V. K.)—383(T)
—— **and Richard F. Baker.** Observation of crystalline reflections in electron microscope images—722(L)
Hippel, A. von, R. J. Maurer, and G. M. Lee. Remarks on the letter of A. E. W. Austen and S. Whitehead. Electric strength of dielectrics—200(L)
Holdeman, Quintin (see Delaup, Paul S.)—726(A)
Horenstein, William (see Lowan, Arnold N.)—94(L)
Horn, F. Hubbard, W. F. Brucksch, Jr., W. T. Ziegler, and D. H. Andrews. Magnetic study of the superconducting transitions of hydrides and nitrides of columbium and tantalum—738(A)
Householder, A. S. (see Weinberg, A. M.)—102(A)
Hudson, George E. Dispersion of sound at high frequencies in cylindrical rods—739(A)
Hudson, Gilbert G. Negative point-to-plane corona in air 205(A)
Hudspeth, Emmett L. (see Ramsey, W. E.)—95(L)
Hughes, A. L. Applications of electron scattering—383(T)
Hughes, Donald J. Cloud-chamber tracks of heavy particles at high altitude—393(A)
Hulthén, Lamek. On the virtual state of the deuteron—671(L)
Hunter, Lloyd and Sidney Siegel. Variation with temperature of the principal elastic moduli of NaCl near the melting point—84
Huntington, H. B. Self-consistent treatment of the vacancy mechanism for metallic diffusion—325
—— **and Frederick Seitz.** Mechanism for self-diffusion in metallic copper—315
Huntoon, R. D. (see Manning, H. P.)—371
Hutter, R. G. E. (see Marton, L.)—205(A)

Inglis, D. R. On the triplets of helium—297
Iona, Mario, Jr. On the lattice vibrations of the KCl crystal—104(A)

Jaffé, George. On a paradox in the theory of heat conduction—635
Jahn, H. A. and K. Lonsdale. Diffuse reflection of x-rays by anisotropic and isotropic solids—375
Johnson, R. P. and W. R. Grams. Secondary scattering of electrons in silicon—671(L)
Johnson, T. H. and R. P. Shutt. Cloud-chamber track of a mesotron stopped by gas—380(L)
Jones, Arthur Taber. Edge tones—724(A)

Kane, Kathleen. Smith College generating voltmeter—99(A)
Kao, Chao-Lan (see Oetjen, Robert A.)—547(A)
Kaplan, J. Efficient green line source—202(A)
Karcher, J. C. Training of physicists for work in geophysics —383(T)
Keller, J. M. (see Christy, R. F.)—147
Kennedy, William R. (see Copeland, Paul L.)—737(A)
Kennon, W. L. and A. B. Cullen. Adaptation of the Anderson bridge for the detection of minute changes in temperature—728(A)
Kent, C. V. (see Cork, J. M.)—388(A)
——, **J. M. Cork, and W. G. Wadey.** Radioactive selenium from arsenic—389(A)
Kenty, Carl. Pressures and temperatures in high pressure mercury lamps—545(A)
Kerst, D. W. New induction accelerator generating 20 Mev —93(L)
Keuffel, J. W. (see Snyder, T. M.)—390(A)
Kinsey, E. L. (see Lyon, Waldo)—482
Klaiber, G. Stanley and Gertrud Scharff-Goldhaber. Photoneutrons produced in beryllium by the γ-rays of radio-antimony (60*d*)—733(A)
Klapman, S. J. (see Rossi, Bruno)—414
Knauss, Harold P. (see Weimer, David K.)—544(A)
Knorr, H. V. (see Albers, V. M.)—546(A)
—— (see Fry, David)—729(T), 730(A)
—— (see Krone, Ralph)—729(T), 730(A)
—— (see Stewart, Albert)—729(T), 729(A)
—— **and V. M. Albers.** Fluorescence and absorption spectra of hydrogenated chlorophyll *a*—546(A)
Koehler, James S. and Frederick Seitz. Calculation of the increase in electrical resistance produced by cold-work —390(A)
Koontz, Phillipp G. (see Rossi, Bruno)—675, 734(A)

Korff, S. A. Counters, their characteristics and the theory of their discharge—673(T)
—— Neutrons produced by the cosmic radiation at 14,170 feet altitude—393(A)
—— **and E. T. Clarke.** Production of neutrons and protons by the cosmic radiation at 14,125 feet—422
Kothari, D. S. (see Gogate, D. V.)—349
Kratz, H. R. Fine structure and series extension in the alkali metal atomic spectra—735(A)
—— (see Mack, J. E.)—735(A)
Krone, Ralph and H. V. Knorr. Spark recording apparatus for simple harmonic motion—729(T), 730(A)
Kulchitsky, L. A. and G. D. Latyshev. Multiple scattering of fast electrons—254
Kurbatov, J. D. (see DeWire, J. W.)—544(A), 564
—— (see Mounce, Katherine E.)—389(A)
—— (see Nelson, Martin E.)—105(A), 428, 733(A)
——, **D. C. MacDonald, M. L. Pool, and L. L. Quill.** Further progress on the study of the radioactive isotopes of the Nd-Il-Sm region—106(A)
Kusaka, S. and J. Weinberg. Quantization of the wave field for particles with spin $\frac{3}{2}$—205(A)

Ladenburg, Rudolf (see Barschall, H. H.)—129
—— **and John A. Wheeler.** Mass of the meson by the method of momentum-loss—105(A)
Lagemann, R. T. Infra-red fundamental of $C^{13}O^{16}$—729(A)
Lanczos, Cornelius. Matter waves and electricity—713
Landahl, H. D. Kinetic theory of mechanical forces in diffusion fields—103(A)
Landé, Alfred (see Thomas, L. H.)—543(A)
—— **and L. H. Thomas.** Finite self-energies in radiation theory—543(A)
Lander, J. J. (see Germer, L. H.)—93(L), 614
Lane, C. T. and W. A. Dodd. Resistivity of antimony-tin single crystals at low temperatures—183, 391(A)
Langmuir, D. B. Crystal planes developed by d.c. heating of tantalum—739(A)
Lapointe, C. (see Feeny, H.)—469
Laporte, Otto. Term formulae for the configuration d^5—302
—— **and John R. Platt.** Degeneracies among terms of a configuration of equivalent electrons—305
Lark-Horovitz, Karl. Every new science teacher a prospective defense training teacher—724(T)
Latyshev, G. D. (see Kulchitsky, L. A.)—254
Lee, G. M. (see Hippel, A. von)—200(L)
Little, J. B. (see Avrami, Melvin)—392(A)
Long, E. C. Check on film speeds—728(A)
Lonsdale, K. (see Jahn, H. A.)—375
Lowan, Arnold N. (see Blanch, G.)—543(A)
—— **and William Horenstein.** On the function $H(m, a, x) = \exp(-ix) F(m+1-ia, 2m+2, 2ix)$—94(L)
Luebke, E. A. (see Manley, J. H.)—152
Lyon, Waldo and E. L. Kinsey. Infra-red absorption spectra of the water molecule in crystals—482

MacDonald, D. C. (see Kurbatov, J. D.)—106(A)
Mack, J. E. and H. R. Kratz. Bands in the vapors of the alkali metal atoms, in a long absorption path—735(A)
MacNair, D. (see Nix, F. C.)—74
MacPherson, H. G. Consumption of the positive arc carbon—392(A)
—— Radiation from the carbon arc—98(T)
Maier, Martin S. Radioactive tracers in industrial research—729(T)
Manley, J. H., L. J. Haworth, and E. A. Luebke. Mean life of neutrons in water and the hydrogen capture cross section—152
Manning, H. P. (see Crenshaw, C. M.)—388(A)
——, **R. D. Huntoon, F. E. Myers, and V. J. Young.** Distribution in angle of protons from the D-D reaction—371
Manning, Millard F. Electronic energy band in body-centered iron—542(A)
—— (see Greene, J. B.)—542(A)
Marcinkowski, Chester (see Hector, L. Grant)—738(A)
Marshak, R. E. Forbidden transitions in β-decay and orbital electron capture and spins of nuclei—388(A), 431
—— (see Blanch, G.)—543(A)
Marton, L. Regulated voltage supplies—204(A)
—— **and R. G. Hutter.** Regulated power supplies—205(A)
Masius, Morton. Physics at Worcester Polytechnic Institute—724(T)
Maurer, R. J. (see Hippel, A. von)—200(L)
Mayhew, George (see Mott, George)—729(T)
McCutcheon, Don M. Some applications of x-ray inspection to defense problems—541(T)
McKay, Kenneth G. Total secondary electron emission from thin films of sodium on tungsten—708
McMahon, J. F. Physical aspects of research in ceramics—101(T)
McNally, J. Rand, Jr. (see Albertson, Walter E.)—167
Meyerott, Roland. Mobility of He^+ in He—738(A)
Miley, H. A. (see Dighton, A. L.)—384(A)
Miller, Carlton W. and C. G. Montgomery. Pulse size as a function of pressure in Geiger-Mueller counters—734(A)
Miller, P. H., Jr. and Floyd R. Banks. Self-diffusion of zinc—648
Millikan, Robert A., H. Victor Neher, and William Pickering. Hypothesis as to the origin of cosmic rays and its experimental testing in India and elsewhere—397
Millman, S. (see Hardy, T. C.)—459
Mills, Carroll B. (see Ballard, Stanley S.)—108(A)
Mohler, Nora M. Sabattier effect—724(A)
Montgomery, C. G. (see Beringer, Robert)—222
—— (see Miller, Carlton W.)—734(A)
Mooney, Rose C. L. Crystal structure of tetraphenyl arsonium tri-iodide—739(A)
Mott, George and George Mayhew. Mechanical method for testing shutter speeds of cameras—729(T)
Mounce, Katherine E., M. L. Pool, and J. D. Kurbatov. Radioactive isotopes of lanthanum—389(A)
Mrozowski, S. Hyperfine structure of the forbidden line λ2967.52 of Hg I—735(A)
—— On the spectra of Hg II and Hg III—605
—— Quenching and depolarization of resonance radiation by collisions with molecules of a foreign gas. Remarks on papers by Ellett, Olsen, and Petersen and by Olsen—379(L)
—— **and F. Bueso-Sanllehí.** Spectrum of Bi I—108(A)

Mueller, Hans and Morris H. Shamos. Magneto-optical properties of ferromagnetic suspensions—631
Mulliken, Robert S. Nature of electronic levels in ultraviolet spectra of hydrogen and alkyl halides—277
—— Some high dispersion grating spectra in the ultraviolet —541(T)
—— **and Edward Teller.** Interpretation of the methyl iodide absorption bands near λ2000—283
—— **and Edward Teller.** Nature of the methyl iodide absorption system near λ2000—107(A)
Mullin, Charles J. (see Guth, Eugene)—339
—— **and Eugene Guth.** Transition from thermionic to cold emission—542(A)
Murray, M. J. (see Cleveland, Forrest F.)—106(A), 386(A), 735(A)
—— (see Saunders, Robert H.)—106(A)
—— (see Tauffen, H. J.)—106(A)
Myers, F. E. (see Manning, H. P.)—371
—— (see Van Atta, L. C.)—99(A)
—— **and L. C. Van Atta.** On the photodisintegration of beryllium and deuterium—19

Neher, H. Victor (see Millikan, Robert A.)—397
—— **and W. H. Pickering.** Results of a high altitude cosmic-ray survey near the magnetic equator—407
Nelson, E. and J. R. Oppenheimer. Pair theories of meson scattering—202(A)
Nelson, Martin E., M. L. Pool, and J. D. Kurbatov. Characteristic radiations of CO^{66}—733(A)
——, **M. L. Pool, and J. D. Kurbatov.** Radioactive isotopes of nickel and their assignments—105(A), 428
Nereson, Norris. Transition curves for electron and photon produced showers—111
Newberry, S. (see Berry, H. W.)—63
Newhall, Herbert F. Proton production by electron collisions in molecular hydrogen—737(A)
Newton, Robert R. and W. H. Shaffer. Valence and central forces in the water vapor molecule—546(A)
Nichols, Myron H. Absorption of thorium on tungsten single crystals—390(A)
Nielsen, Carl E. Efficiency of positive and negative ions as condensation nuclei in the Wilson cloud chamber—202(A)
Nielsen, Harald H. Coriolis interaction and the infra-red spectra of certain polyatomic molecules—541(T)
—— Errata: Vibration-rotation energies of polyatomic molecules—540(L)
Nielsen, J. Rud. Applications of spectroscopy to the oil industry—383(T)
—— **and Newton E. Ward.** Raman spectra of compounds in the gaseous and liquid states—383(A)
Nix, F. C. and D. MacNair. Thermal expansion of pure metals II: molybdenum, palladium, silver, tantalum, tungsten, platinum, and lead—74
Nordheim, L. W. (see Richards, J. A., Jr.)—735(A)
Norwood, J. N. Address of welcome—101(T)

Oetjen, Robert A., Chao-Lan Kao, and H. M. Randall. Performance and calibration of a recording infra-red spectrometer—547(A)
Oldenberg, O. (see Clark, K. C.)—100(A)
Oliver, Anne Rebecca. Structure of evaporated films of chromium and aluminum on glass—313
Oppenheimer, J. R. (see Nelson, E.)—202(A)

Page, Aileen. Home lighting demonstration—98(T)
Parratt, L. G. (see Platt, J. B.)—103(A)
—— (see Trischka, J. W.)—103(A)
Paschkis, Victor (see Avrami, Melvin)—394(A)
Pauli, W. (see Dancoff, S. M.)—387(A)
Paulus, Alfred. Sterilizing with ultraviolet radiation—98(T)
Pearson, G. L. Thermistors, their characteristics and uses—100(T)
Pelsor, Gene T. Vibrational analysis of the 3200A band system of CS_2—384(A)
Pepinsky, R. Space group and lead positions in lead gluconate—726(A)
Perkins, Henry A. Some quasi-hysteresis cycles—724(A)
Petrauskas, A. A. (see Van Atta, L. C.)—99(A)
Pickering, William H. (see Millikan, Robert A.)—397
—— (see Neher, H. V.)—407
Picton, Dean C. (see Goodman, Clark)—99(A)
Pincherle, Leo. Rydberg corrections for *D*-terms in He I—156
—— X-ray *L*-series satellite lines—225
Platt, John R. (see Laporte, Otto)—305
Platt, J. B. and L. G. Parratt. X-ray absorption structure in the region of the potassium *K* edge—103(A)
Pollard, W. G. Effect of double layer on the forces between neutral molecules and metal surfaces—740(A)
Pool, M. L. (see DeWire, J. W.)—544(A), 564
—— (see Kurbatov, J. D.)—106(A)
—— (see Mounce, Katherine E.)—389(A)
—— (see Nelson, Martin E.)—105(A), 428, 733(A)
Posey, L. R. and E. F. Barker. Comparison of certain infra-red bands in C_2H_6, C_2D_6, and C_2H_5D—546(A)
Powell, Wilson M. Electrons and heavier particles at 14,125 feet—202(A)
—— Production of mesotrons, "stars," cascade showers produced by penetrating rays, slow protons, evidence for the disintegration electron—206(A)
—— Stars and slow protons at 14,125 feet—670(L)
Primakoff, H. Translational dispersion of sound in gases—740(A)
Prosen, E. J. R. and R. G. Sachs. Interaction between a molecule and a metal surface—65

Quill, L. L. (see Kurbatov, J. D.)—106(A)
Quimby, Edith H. Physical methods of dosage determination in x-ray therapy—724(T)
Quimfe, Germaine (see Heller, Wilfried)—382(L)

Racah, Giulio. On a new type of vector coupling in complex spectra—537(L)
—— On the deep configuration of cobalt—537(L)
—— Theory of complex spectra. I—186
Ramsey, W. E. Directional properties of self-quenching counters—96(L)
—— (see Rose, M. E.)—198(L), 504
—— **and Emmett L. Hudspeth.** Some discharge characteristics of self-quenching counters—95(L)

Randall, H. M. Precision measurements with the infra-red recording prism spectrometer—541(T)
—— (see Oetjen, Robert A.)—547(A)
Rasetti, F. (see Feeny, H.)—469
Rathgeber, Henri D. Mesotron component of cosmic rays—207
Rayton, Willis. Defense training course in radio techniques—98(T)
Regener, Victor H. Production of penetrating particles in the cosmic radiation—734(A)
—— Production of penetrating particles on Mt. Evans—105(A)
Reid, Walter P. Effect of high electrostatic fields upon the vaporization and resistance of molybdenum filaments—737(A)
Richards, A. Glenn, Jr. and Thomas F. Anderson. Electron micrograph studies of insect structures—383(T)
Richards, J. A., Jr. and L. W. Nordheim. Energy distribution in showers at low energies—735(A)
Richardson, W., H. Vance White, and Bertha H. Weaver. X-ray analysis of the time-softening property of a lead-tin alloy—728(A)
Richman, C. Angular distribution in deuteron disintegration by electrons—203(A)
Riddle, Frank. Ceramic insulators for spark plugs—541(T)
Roberg, Jane. Theory of the lateral spread of cosmic-ray showers—735(A)
Roberts, A. (see Deutsch, M.)—389(A)
—— (see Downing, J. R.)—389(A), 686
—— (see Elliott, L. G.)—99(A)
Rodgers, Eric. Scattering of polarized x-rays by ferromagnetic substances—35
Rogers, Eric. Demonstration experiments with tuning forks—100(T)
Rogers, F. T., Jr. Note on the analysis of single-scattering data—728(A)
—— On photometry with the photoelectric cell—394(A)
Rogers, H. W. Physics and chemistry in crime detection—725(T)
Rose, M. E. Energy distribution of mesotrons—394(A)
—— **and W. E. Ramsey.** Behavior of proportional counter amplification at low voltages—198(L)
—— **and W. E. Ramsey.** Proportional counter amplification at low voltages—504
Rosen, Nathan. Interpretation of wave mechanics—726(A)
—— **and Arthur E. Ruark.** Quantum mechanical systems with generalized Hamiltonians—727(A)
Rosenberg, Paul. Evaluation of functions related to Tait's mean free path—528
Rossi, Bruno and Kenneth Greisen. Origin of the soft component of cosmic rays—121
—— **and S. J. Klapman.** Cosmic-ray electrons of low energy in the atmosphere—414
——, **Kenneth Greisen, Joyce C. Stearns, Darol K. Froman, and Phillipp G. Koontz.** Further measurements of the mesotron lifetime—675, 734(A)
Ruark, Arthur E. Condensation due to adiabatic compression—727(A)
—— (see Rosen, Nathan)—727(A)
Sachs, R. G. (see Prosen, E. J. R.)—65
—— **and Julian Schwinger.** On the magnetic moments of H^3 and He^3—732(A)
Sanford, William. Running a high school science club—101(T)
Sauer, J. A. On the adiabatic demagnetization of iron alum—738(A)
Saunders, Robert H. (see Cleveland, Forrest F.)—386(A)
——, **M. J. Murray, and Forrest F. Cleveland.** Raman spectra evidence for hindrance of resonance by ortho-substitution—106(A)
Sawyer, Ralph A. (see Boyd, Robert A.)—601
—— (see Wheatley, Marshall A.)—591
Scharff-Goldhaber, Gertrud (see Klaiber, G. Stanley)—733(A)
Schein, Marcel, David B. Hall, and Jane Hamilton-Hall. Variation of intensity of cosmic rays with zenith angle at 14,200 feet altitude—105(A)
Scherrer, P. (see Bleuler, E.)—95(L)
Schiff, L. I. Atomic images with the electron microscope—391(A)
—— Ultimate resolving power of the electron microscope—721(L)
Schuchard, E. A. Units in mechanics—384(T)
Schwarz, W. M. A voltage stabilizer for a d.c. generator—544(A)
Schwinger, Julian. On a field theory of nuclear forces—387(A)
—— (see Gerjuoy, Edward)—138
—— (see Sachs, R. G.)—732(A)
Scott, L. B. (see Barr, E. S.)—728(A)
—— (see Elliott, D. S.)—727(A)
Sears, Francis W. Stroboscopic photographs used in the teaching of mechanics—98(T)
Segrè, E. (see Wu, C. S.)—203(A)
Seitz, Frederick (see Huntington, H. B.)—315
—— (see Koehler, James S.)—390(A)
Serber, R. (see Dancoff, S. M.)—394(A)
Shaffer, W. H. (see Newton, Robert R.)—546(A)
Shamos, Morris H. (see Mueller, Hans)—631
Shapiro, Maurice M. Frequency of proton and alpha-tracks in cosmic-ray "stars"—115
—— Statistical study of cosmic-ray "star" tracks in a photographic emulsion—104(A)
Shearin, Paul E. Abnormal scattering of electrons—736(A)
Sherman, H. A. Report of the A.P.T. committee on the teaching of physics in secondary schools—725(T)
Sherr, R. Collision cross sections of C and H for 25-Mev neutrons—734(A)
Shull, Clifford G. Electron polarization—198(L), 736(A)
—— Polarization of electrons—673(T)
Shutt, Ralph P. On the electrical and anomalous scattering of mesotrons—6
—— (see Johnson, T. H.)—380(L)
Siegel, Sidney. Ferromagnetic anisotropy of an Fe-Al alloy—390(A)
—— (see Hunter, Lloyd)—84
Silver, Samuel. Vibration-rotation energies of planar ZXY_2 molecules—383(A)

Simon, Ralph. Isotope separation factor of a thermal diffusion column—388(A)
Slepian, J. New method for deriving poynting and other valid energy flow vectors—732(A)
Smith, Charles G. Mercury arc cathode—545(A)
Smith, Charles S. (see Weigle, J.)—23
Smith, Gail P. Beta-ray spectra of scandium—578
Smith, Lincoln G. and W. M. Woodward. Fine structure of the infra-red bands of C_2H_6—386(A)
Smith, R. N. Isometric states in indium^{112}—389(A)
Smoluchowski, R. Electronic structure and polymorphism of iron alloys—390(A)
—— Influence of 1-quantum number on the structure of x-ray absorption edges—736(A)
Snyder, T. M., J. W. Keuffel, J. J. Gilvarry, and K. Way. Temperature dependence of slow neutron resonance absorption in silver—390(A)
Sponer, H. (see Beck, C. A.)—386(A)
—— **and Maurice B. Hall.** Absorption spectrum of symtrichlorobenzene vapor—107(A)
Staker, William Paul. Thermal expansion of single and optically mosaic zinc crystals—653
Stallcup, W. David and Dudley Williams. Infra-red absorption of silver cyanide—726(A)
Stearns, Joyce C. (see Rossi, Bruno)—675, 734(A)
Stephenson, E. A. Training of students for work in the petroleum industry—383(T)
Stever, H. G. Discharge mechanism of fast G-M counters from the deadtime experiment—38
Stewart, Albert, H. V. Knorr, and V. M. Albers. Chemiluminescence spectrum of chlorophyll *a*—729(T), 729(A)
Stier, L. G. Coefficient of thermal diffusion of argon and its variation with temperature—740(A)
Sullivan, R. R. Specific surface measurements on compact bundles of parallel fibers—727(A)
Swann, W. F. G. Origin of statistical fluctuations in proportional Geiger counters—734(A)
—— **and Paul Weisz.** Ionization of individual cosmic rays —392(A)
Swift, Irvin H. and E. P. T. Tyndall. Elasticity and creep of Pb single crystals—359

Taschek, R. F. Scattering of protons by deuterium—13
Tatel, Howard. Angular distribution of protons scattered by high energy neutrons—450
Tauffen, H. J., M. J. Murray, and Forrest F. Cleveland. Raman spectra of *dl*- and meso-2,3-dibromobutane—106(A)
Teague, Donald S. Non-Laue reflections from various crystals—204(A)
Teller, Edward (see Mulliken, Robert S.)—107(A), 283
Thomas, L. H. (see Landé, Alfred)—543(A)
—— **and Alfred Landé.** Self-energy of the electron—543(A)
Thomas, Roy (see Bohm, D. J.)—203(A)
Thomson, Earl W. Aviation problems in elementary physics—384(T)
Tisza, L. On the quantization problem in hydrodynamics—731(A)
—— Supersonic absorption and Stokes' viscosity relation —531
Trischka, J. W. and L. G. Parratt. Electronic stabilizer for 1 to 50 kv and 20 to 500 ma—103(A)
Tsien, San-Tsiang (see Beck, G.)—379(L)
Tyndall, E. P. T. (see Swift, Irvin H.)—359

Ufford, C. W. and E. P. Wigner. On the calculation of the distribution function—524
Uhlenbeck, G. E. (see Wang, Ming Chen)—106(A)
—— **and R. J. Bessey.** Application of the W. K. B. approximation to the radial Dirac equations for the hydrogen atom—544(A)

Van Atta, L. C. (see Myers, F. E.)—19
——, **F. E. Myers, and A. A. Petrauskas.** Measurements on x-ray production and absorption in the range 0.7 to 2.5 Mv—99(A)
Varney, R. N. (see Berry, H. W.)—63
Vineyard, George H. Oriented overgrowths of alkali halides on MgO—100(A)
Vissat, Peter L. Effect of high electrostatic fields on the conductivity of tungsten—737(A)

Wadey, W. G. (see Kent, C. V.)—389(A)
Wager, A. T. Perturbations in the $b^2\epsilon$, $v=0$ band of cyanogen—107(A)
Wahlin, H. B. Thermionic properties of the iron group—103(A), 509
Wang, Kan Chang. Suggestion on the detection of the neutrino—97(L)
Wang, Ming Chen. On the proof of the Maxwell-Boltzmann distribution law—543(A)
—— **and G. E. Uhlenbeck.** Note on a problem of Rayleigh —106(A)
Wannier, Gregory H. Remark concerning liquid specific heats—391(A)
Wantland, Dart. Electrical methods in prospecting—383(T)
Warburton, F. W. Magnetic force of charge on charge—732(A)
Ward, Newton E. (see Nielsen, J. Rud)—383(A)
Way, K. (see Snyder, T. M.)—390(A)
Weaver, Bertha H. (see Richardson, W.)—728(A)
Webb, J. H. Reciprocity law failure and intermittency effect in photographic exposure—101(T)
Weber, Louis R. Up-to-date experiments for the laboratory —384(T)
—— **and Frank P. Goeder.** Velocity of sound in methyl methacrylate polymer—94(L)
Weigle, J. and Charles S. Smith. Thermal scattering of x-rays in crystals—23
Weimer, David K. and Harold P. Knauss. A.c. resonant pendulum without iron—544(A)
Weinberg, A. M. and A. S. Householder. Statistical distribution of impedance elements in biological systems—102(A)
Weinberg, J. (see Kusaka, S.)—205(A)
Weinstock, Robert. Theory of intensity and polarization of continuous x-radiation—204(A)
—— Theory of the continuous x-ray spectrum—584
Weiss, P. R. On the Heisenberg theory of ferromagnetism —387(A)

Weissler, Gerhard L. Properties of coronas in pure and impure H_2, N_2, and A—205(A)
Weisz, Paul. Self-quenching Geiger-Mueller counters—392(A)
—— (see Swann, W. F. G.)—392(A)
Welles, S. B. Electric quadrupole moments of light and heavy nuclei—732(A)
Wheatley, Marshall A. and Ralph A. Sawyer. First spark spectrum of caesium (Cs II)—591
Wheeler, John A. (see Ladenburg, Rudolf)—105(A)
Wheeler, Lisle L. and S. Leroy Brown. Mechanical means for the graphical representation and solution of transcendental functions—383(A)
White, H. Vance (see Richardson, W.)—728(A)
Whitehead, S. (see Austen, A. E. W.)—199(L)
Wigner, Eugene P. Systems with many particles—101(T)
—— (see Ufford, C. W.)—524
Williams, Dudley (see Stallcup, W. David)—726(A)
Williams, John H. (see Bailey, Carl L.)—539(L)
Wilson, Robert R. (see Creutz, Edward C.)—388(A)
Witmer, Enos E. Calculation of the magnetic susceptibility of H_2, HD, and D_2 by quantum mechanics—387(A)
Wold, William E. Address of welcome—725(T)
Wood, R. W. Replica gratings for large Schmidt telescopes—735(A)
Woodward, W. M. (see Smith, Lincoln G.)—386(A)
Worrell, Francis T. V^3I relation for vaporizing molybdenum—520
Wright, Norman. Application of a lithium fluoride prism in infra-red spectroscopy—541(T)
Wrinch, Dorothy. Native protein, a problem for physics—98(T)
Wu, C. S. and E. Segrè. Artificial radioactivity of some rare earths—203(A)

Yost, F. F. Fatigue characteristics of rubber—541(T)
Young, V. J. (see Crenshaw, C. M.)—388(A)
—— (see Manning, H. P.)—371

Zacharias, J. R. Nuclear spin and magnetic moment of K^{40}—270
Zachariasen, W. H. Further theoretical studies of the temperature diffuse x-ray scattering—103(A)
Zeleny, John. Mechanism of the electric spark—738(A)
Ziegler, W. T. (see Horn, F. Hubbard)—738(A)
Zünti, W. (see Bleuler, E.)—95(L)
Zwicky, F. On the large scale distribution of matter in the universe—489
Zworykin, V. K. and J. Hillier. Stereo-microscopy with the electron microscope—383(T)

Analytic Subject Index to Volume 61

References with (A) are to abstracts of papers presented at meetings of the American Physical Society. References with (L) are to Letters to the Editor.

Acoustics
Absorption in gases, Pierce interferometer, H. C. Hardy—740(A)
Analysis of city noises, D. S. Elliott, L. B. Scott—727(A)
Dispersion in gases, H. Primakoff—740(A)
Dispersion at high frequencies in rods, G. E. Hudson—739(A)
Edge tones, A. T. Jones—724(A)
Supersonic absorption, L. Tisza—531
Ultrasonic fields, W. Garten—391(A)
Velocity of sound in lucite, L. R. Weber, F. P. Goeder—94(L)
Afterglow
Effect of temperature, D. E. Debeau—668
Green line source, J. Kaplan—202(A)
Alloys (see **Crystalline states**)
Arcs (see **Discharge of electricity in gases**)
Astrophysics
Distribution of matter in universe, F. Zwicky—489
Gratings for Schmidt telescopes, R. W. Wood—735(A)
Temperature-density distribution of Sirius A, G. Blanch, A. N. Lowan, R. E. Marshak, H. A. Bethe—543(A)
Biophysics
Chemiluminescence of chlorophyll *a*, A. Stewart, H. V. Knorr, V. M. Albers—729(A)
Impedance elements in biological systems, A. M. Weinberg, A. S. Householder—102(A)
Mechanical forces in diffusion, H. D. Landahl—103(A)
Nerve fiber impedance, K. S. Cole—391(A)
Chemical reactions
Oxidation of Cu, A. L. Dighton, H. A. Miley—384(A)
Sabattier effect, N. M. Mohler—724(A)
Conductivity, electrical (see **Electrical conductivity; Discharge of electricity in gases**)
Conductivity, thermal (see **Thermal conductivity**)
Constants, physical, Standards
Electronic charge, R. T. Birge—206(A)
Fine structure constant from x-ray splitting, R. F. Christy, J. M. Keller—147
Value of Faraday, R. T. Birge—204(A)
Contact potentials
Anode effect in a triode, P. L. Copeland, G. G. Carne—103(A), 635
Theory of electrical contact, H. Y. Fan—365

Cosmic radiation
Absorption of extensive showers, P. Auger, J. Daudin —91
Cloud-chamber photographs at 4310 m, W. H. Bostick —104(A), 557
Cosmic-ray geomagnetic relation, F. Evans—545(A)
Diurnal variation of extensive showers, P. Auger, J. Daudin—95(L)
Electric and magnetic effects, F. Evans—680
Electrons of low energy in atmosphere, B. Rossi, S. J. Klapman—414
Electrons and particles at 14,125 ft., W. M. Powell—202(A)
Energy distribution of mesotrons, M. E. Rose—394(A)
Energy distribution in showers, J. A. Richards, Jr., L. W. Nordheim—735(A)
Fluctuations in proportional counters, W. F. G. Swann —734(A)
Hard and soft components, intensities of, K. Greisen —212
Height of air mass, mesotron intensity, V. F. Hess, G. O. Altmann—393(A)
High altitude survey near magnetic equator, H. V. Neher, W. H. Pickering—407
Hypothesis as to origin; tests, R. A. Millikan, H. V. Neher, W. H. Pickering—397
Ionization of He by cosmic rays, W. E. Hazen—202(A)
Ionization of individual rays, W. F. G. Swann, P. Weisz —392(A)
Measurements between New York and Valparaiso, E. B. Berry, S.J.—394(A)
Mesotron component, H. D. Rathgeber—207
Mesotrons in air showers, W. H. Bostick—104(A)
Mesotrons, dual telescope, F. A. Benedetto, G. O. Altmann, V. F. Hess—266
Mesotrons, "stars," cascade showers, W. M. Powell—206(A)
Neutrons and protons at 14,125 ft., S. A. Korff—393(A); S. A. Korff, E. T. Clarke—422
Origin of soft component, B. Rossi, K. Greisen—121
Penetrating particles on Mt. Evans, V. H. Regener—105(A)
Penetrating power of extensive shower particles, N. Hilberry, A. H. Hilberry—393(A)
Production of penetrating particles, V. H. Regener—734(A)
Proton and α-tracks in "stars," M. M. Shapiro—104(A), 115
Secondary effects of penetrating radiation, P. Auger, J. Daudin—549
Soft component of 3500 m, P. V. Auger—684
Solar influence on intensity, J. W. Broxon—545(A)
Stars and slow protons, W. M. Powell—670(L)
Theory of lateral spread, J. Roberg—735(A)
Track of mesotron, T. H. Johnson, R. P. Shutt—380(L)
Tracks of heavy particles, D. J. Hughes—393(A)
Transition curves for showers, N. Nereson—111
Variation of with zenith angle, M. Schein, D. B. Hall, J. Hamilton-Hall—105(A)

Crystal structure
Crystal planes developed by d.c. heating, D. B. Langmuir—739(A)
Of $Pb(C_6H_{11}O_7)_2$, R. Pepinsky—726(A)
Overgrowths of alkali halides on MgO, G. H. Vineyard —100(A)
Polymorphism of Fe alloys, R. Smoluchowski—390(A)
Of tetraphenyl arsonium tri-iodide, R. C. L. Mooney—739(A)

Crystalline state
Sb—Sn single crystals, resistivity, C. T. Lane, W. A. Dodd—391(A), 183
Crystalline reflections, electron microscope, J. Hillier, R. F. Baker—722(L)
Electrical contact, H. Y. Fan—365
Electronic energy band in body-centered iron, M. F. Manning—542(A)
Electronic energy bands in face-centeréd iron, J. B. Greene, M. F. Manning—542(A)
Interaction between molecule and metal surface, E. J. R. Prosen, R. G. Sachs—65
Lattice vibrations of KCl crystal, M. Iona, Jr.—104(A)
Order-disorder in spinels, F. C. Blake—729(A)
Order in alloy Cu_3Au, L. H. Germer, F. E. Haworth, J. J. Lander—93(L), 614
Properties of ionic crystals, K. Fajans—543(A)
Submicroscopically twinned crystals, F. C. Blake—108(A)
Time-softening property of Pb-Sn alloy, W. Richardson, H. V. White, B. H. Weaver—728(A)

Dielectrics and dielectric properties
Absorption in cellulose nitrate, C. L. Burke—100(A)
Changes with temperature and composition in solids, R. F. Field—737(A)
Electric strength of dielectrics, A. E. W. Austen, S. Whitehead—199(L); H. Fröhlich—200(L); A. von Hippel, R. J. Maurer, G. M. Lee—200(L)
Field of electrets, A. Gemant—79

Diffraction of electrons (see **Electron diffraction**)

Diffusion (see also **Thermal diffusion**)
Of heat through rectangular bar, M. Avrami, J. B. Little—392(A)
Kinetic theory of mechanical forces, H. D. Landahl—103(A)
Self-diffusion in Cu, H. B. Huntington, F. Seitz—315
Self-diffusion of Zn, P. H. Miller, Jr., F. R. Banks—648
Vacancy mechanism for metallic diffusion, H. B. Huntington—325

Discharge of electricity in gases
Consumption of positive arc carbon, H. G. MacPherson —392(A)
Coronas in pure H_2, N_2, and A, G. L. Weissler—205(A)
Distribution of current from a point, W. H. Bennett—53
Mechanism of electric spark, J. Zeleny—738(A)
Mercury arc cathode, C. G. Smith—545(A)
Point-to-plane corona, G. G. Hudson—205(A)
Positive corona phenomena, K. E. Fitzsimmons—175

Disintegration and excitation of nucleus (see also **Radioactivity**)
Deuteron disintegration by electrons, C. Richman—203(A)
Deuteron-tritium reaction in N and F, L. B. Borst—106(A)
Distribution of protons from D-D reaction, H. P. Manning, R. D. Huntoon, F. E. Myers, V. J. Young—371
Photodisintegration of Be and D, F. E. Myers, L. C. Van Atta—19
Probability of D,2*n* and D,*n* reactions in Ni and Zn, J. M. Cork, L. N. Hadley, Jr., C. V. Kent—388(A)
Yield of Na^{24} under deuteron bombardment, C. L. Bailey, J. H. Williams—539(L)
Dissociation
Protons by electron collisions in H_2, H. F. Newhall—737(A)

Elasticity
Equations of state for rubber, R. H. Caston, R. L. Anthony, E. Guth—542(A)
Of Pb single crystals, I. H. Swift, E. P. T. Tyndall—359
Moduli of NaCl near melting, L. Hunter, S. Siegel—84
Neoprene under periodic stress, M. L. Braun—728(A)
Rubber in vibration, S. D. Gehman—542(A)
Velocity of sound in lucite, L. R. Weber, F. P. Goeder—94(L)
Vibrations of incomplete "free-free" circular rings, F. P. Bundy, C. W. Bankes—739(A)
Electrical conductivity and resistance
Of Sb-Sn single crystals at low temperatures, C. T. Lane, W. A. Dodd—391(A), 183
Effect of cold-work, J. S. Koehler, F. Seitz—390(A)
Of hydrocarbons, reaction rates, N. Davidson—721(L)
Superconducting transitions of hydrides and nitrides, F. H. Horn, W. F. Brucksch, Jr., W. T. Ziegler, D. H. Andrews—738(A)
Of titanium dioxide, M. D. Earle—56
Of wires in high electric fields, P. L. Vissat—737(A)
Electromagnetic theory
Finite self-energies, A. Landé, L. H. Thomas—543(A)
Magnetic force of charge on charge, F. W. Warburton—732(A)
Poynting and other energy flow vectors, J. Slepian—732(A)
Self-energy of electron, L. H. Thomas, A. Landé—543(A)
Electron diffraction
Patterns produced by secondary scattering, L. H. Germer—309
In silicon, R. P. Johnson, W. R. Grams—671(L)
Electrons
Electron polarization, C. G. Shull—198(L)
Value of charge, R. T. Birge—206(A)
Electrons, scattering of
Abnormal scattering of, search for, P. E. Shearin—736(A)
From Be coated plates, P. L. Copeland, W. R. Kennedy—737(A)
From films of Na, K. G. McKay—708

Equations of state
For stressed rubber, R. H. Caston, R. L. Anthony, E. Guth—542(A)
Errata
Vibration-rotation energies of polyatomic molecules, H. H. Nielsen—540(L)
Evaporation
Condensation, adiabatic compression, A. E. Ruark—727(A)
Of metals, effect of high electrostatic fields, W. P. Reid—737(A)
V^3I relation for Mo, F. T. Worrell—520

Field currents
Transition from thermionic emission, E. Guth, C. J. Mullin—339, 542(A)
From tungsten single crystals, J. H. Daniel—657
Films, properties of
Of Cr and Al on glass, A. R. Oliver—313

Hall effect
In cuprous oxide, S. J. Angello—391(A)
Heat conduction (see **Thermal conductivity**)
Hydrodynamics
Quantization problem, L. Tisza—731(A)
Hyperfine structure (see also **Nuclear moments and spin**)
Of Bi I, S. Mrozowski, F. Bueso-Sanllehí—108(A)
Of Cs II, R. A. Boyd, R. A. Sawyer—601
λ2967.52 of Hg I, S. Mrozowski—735(A)

Ionization by collision
Of gases by collision with similar molecules, H. W. Berry, R. N. Varney, S. Newberry—63
Of neutral atoms, H. W. Berry—392(A)
Protons by electron collisions in H_2, H. F. Newhall—737(A)
Ions, mobility
Of He^+ in He, R. Meyerott—738(A)

Kinetic theory of gases
Functions related to Tait's mean free path, P. Rosenberg—528

Liquids (see also **Hydrodynamics**)
Two-dimensional phase, W. D. Harkins, L. E. Copeland, G. E. Boyd—104(A)

Magnetic properties
Adiabatic demagnetization of Fe alum, J. A. Sauer—738(A)
Ferromagnetic anisotropy of Fe-Al alloy, S. Siegel—390(A)
Heisenberg theory, P. R. Weiss—387(A)
Magnetic current in gases, F. Ehrenhaft—733(A)
Magnetic current in liquids, L. Banet—733(A)
Quasi-hysteresis cycles, H. A. Perkins—724(A)
Susceptibility of H_2, HD, and D_2, E. E. Witmer—387(A)
Magneto-optical effects
In ferromagnetic suspensions, H. Mueller, M. H. Shamos—631

Mechanics, quantum—atomic structure and spectra
Radial Dirac equations for H, G. E. Uhlenbeck, R. J. Bessey—544(A)
Mechanics, quantum—general
Interpretation of wave mechanics, N. Rosen—726(A)
Magnetic susceptibility of H_2, HD, and D_2, E. E. Witmer—387(A)
Quantization of wave field, S. Kusaka, J. Weinberg—205(A)
Systems with generalized Hamiltonians, N. Rosen, A. E. Ruark—727(A)
Mechanics, statistical
Calculation of a distribution function; long range forces, C. W. Ufford, E. P. Wigner—524
Proof of Maxwell-Boltzmann distribution, Ming-Chen Wang—543(A)
Mesotrons
In cosmic-ray showers, W. H. Bostick—104(A)
With dual telescope, F. A. Benedetto, G. O. Altmann, V. F. Hess—266
Effect of height of air mass, V. F. Hess, G. O. Altmann—393(A)
Energy and absorption in Pb, D. B. Hall—105(A)
Energy distribution, M. E. Rose—394(A)
Mass by momentum-loss, R. Ladenburg, J. A. Wheeler—105(A)
Measurements of lifetime, B. Rossi, K. Greisen, J. C. Stearns, D. K. Froman, P. G. Koontz—676, 734(A)
Slowing of neutrons, Ming-Chen Wang, G. E. Uhlenbeck—106(A)
Theories of scattering, E. Nelson, J. R. Oppenheimer—202(A)
Methods and instruments
Atomic images with electron microscope, L. I. Schiff—391(A)
Autoradiography of ores, C. Goodman, D. C. Picton—99(A)
Condensation, adiabatic compression, A. E. Ruark—727(A)
Condensation nuclei in cloud chamber, C. E. Nielsen—202(A)
Counter amplification at low voltages, M. E. Rose, W. E. Ramsey—198(L), 504
Crystal planes developed by d.c. heating, D. B. Langmuir—739(A)
Crystalline reflections, electron microscope, J. Hillier, R. F. Baker—722(L)
Detecting x-rays, comparison of methods, A. Eisenstein, N. S. Gingrich—104(A)
Detection of minute changes in temperature, W. L. Kennon, A. B. Cullen—728(A)
Detection of neutrino, Kan Chang Wang—97(L)
Determination of traces of K, S. S. Ballard, C. B. Mills—108(A)
Determination of vibration properties, S. D. Gehman—542(A)
Electric model of two-dimensional heat flow, M. Avrami, V. Paschkis—394(A)
Electron microscope, resolving power, L. I. Schiff—721(L)
Electronic stabilizer, J. W. Trischka, L. G. Parratt—103(A)
Electronically controlled capacity, L. G. Hector, G. Guernsey, C. Marcinkowski—738(A)
Fluctuations in proportional counters, W. F. G. Swann—734(A)
γ-radiation from Na^{24}, L. G. Elliott, M. Deutsch, A. Roberts—99(A)
Generating voltmeter, K. Kane—99(A)
Gratings for Schmidt telescopes, R. W. Wood—735(A)
Green line source, J. Kaplan—202(A)
High pressure Hg lamps, C. Kenty—545(A)
Induction accelerator generating 20 Mev, D. W. Kerst—93(L)
Mass spectrometer of wide adaptability, N. D. Coggeshall—738(A)
Mathematical tables, A. N. Lowan, W. Horenstein—94(L)
Mechanism of fast G-M counters, H. G. Stever—38
Mercury arc cathode, C. G. Smith—545(A)
Multiharmonograph, applications of, S. L. Brown—205(A)
Noise measurements, D. S. Elliott, L. B. Scott—727(A)
Photometry with photoelectric cell, F. T. Rogers, Jr.—394(A)
Pulse size in G-M counters, C. W. Miller, C. G. Montgomery—734(A)
Recording infra-red spectrometer, R. A. Oetjen, Chao-Lan Kao, H. M. Randall—547(A)
Regulated power supplies, L. Marton, R. G. E. Hutter—205(A)
Resonant pendulum, D. K. Weimer, H. P. Knauss—544(A)
Self-quenching counters, directional properties, W. E. Ramsey—96(L)
Self-quenching counters, discharge characteristics, W. E. Ramsey, E. L. Hudspeth—95(L)
Self-quenching G-M counters, P. Weisz—392(A)
Separation of nuclear isomers, E. P. Cooper—1
Solution of transcendental functions, L. L. Wheeler, S. L. Brown—383(A)
Spark recording apparatus, R. W. Krone, H. V. Knorr—730(A)
Specific surface measurements, fibers, R. R. Sullivan—727(A)
Standard for chlorophyll preparations, V. M. Albers, H. V. Knorr—546(A)
Test for Hg vapor, K. C. Clark, O. Oldenberg—100(A)
Ultrasonic fields, optical and electromechanical comparisons, W. Garten—391(A)
Voltage stabilizer for d.c. generator, W. M. Schwarz—544(A)
Voltage supplies, regulated, L. Marton—204(A)
Mobility of ions (see **Ions, mobility**)
Molecular structure and constants (see also **Spectra, molecular, etc.,** and **Raman spectra**)
Bond energies in protein fabrics, G. A. Anslow—547(A)
Potential energy curve of KH, G. M. Almy, A. C. Beiler—476
Valence and central forces in H_2O molecule, R. R. Newton, W. H. Shaffer—546(A)

Neutrino (see also **Radioactivity; Scattering of electrons, neutrons and ions**)
Detection of, Kan Chang Wang—97(L)
Experimental evidence for, J. S. Allen—692
Neutrons
Absorption in Ag, temperature dependence, T. M. Snyder, J. W. Keuffel, J. J. Gilvarry, K. Way—390(A)
Elastic and inelastic scattering, H. H. Barschall, R. Ladenburg—129
Magnetic scattering, F. Bloch, M. Hamermesh—203(A)
Mean life in water, J. H. Manley, L. J. Haworth, E. A. Luebke—152
Photoneutrons produced in Be, G. S. Klaiber, G. Scharff-Goldhaber—733(A)
• Produced by cosmic radiation, S. A. Korff—393(A)
Resonance absorption in Rb, Sb, and Au, H. Feeny, C. Lapointe, F. Rasetti—469
Nuclear moments and spin (see also **Hyperfine structure**)
Of H^3 and He^3, R. G. Sachs, J. Schwinger—732(A)
Of In, radiofrequency spectrum, T. C. Hardy, S. Millman—459
Of K^{40}, J. R. Zacharias—270
Theory of higher spins, M. Dresden—733(A)
Nuclear structure (see also **Disintegration and excitation of nucleus**)
Field theory of nuclear forces, J. Schwinger—387(A)
Levels of compound Li_5, G. Beck, San-Tsiang Tsien—379(L)
Mesotron theory of nuclear interactions, S. M. Dancoff, W. Pauli—387(A)
Nuclear Coulomb energy, E. Feenberg—387(A)
Nuclear forces, coupling theory, S. M. Dancoff, R. Serber—394(A)
Quadrupole moments of nuclei, S. B. Welles—732(A)
Tensor forces, theory of light nuclei, E. Gerjuoy, J. Schwinger—138
Theory of H^5, H. Feshbach—544(A)
Virtual state of deuteron, L. Hulthén—671(L)

Optical constants and properties
Of Cu and Be, M. P. Givens—626
Inherent and photoelastic anisotropy, W. Heller, G. Quimfe—382(L)
Optical instruments (see **Methods and instruments**)

Photography
Darkening of plate by Zn, P. S. Delaup, Q. Holdeman—726(A)
Film speeds, E. C. Long—728(A)
Gray scales, preparation of, E. S. Barr, L. B. Scott—728(A)
Photometry
With photoelectric cell, F. T. Rogers, Jr.—394(A)
Positrons
Annihilation radiation, R. Beringer, C. G. Montgomery—222
Proceedings of the American Physical Society
Ohio Section: Cleveland, Ohio, Meeting, October 10–11, 1941—98
New England Section: Northampton, Massachusetts, Meeting, October 11, 1941—98
Metropolitan Section, Meeting, October 31, 1941—100
New York State Section: Alfred, New York, Meeting, November 1, 1941—101
Chicago, Illinois, Meeting, November 21–22, 1941—101
Stanford University, California, Meeting, December 19, 1941—202
Dallas Meeting of Section B, A.A.A.S., and the American Association of Physics Teachers, December 29–30, 1941—383
Princeton, New Jersey, Meeting, December 29–31, 1941—384
Michigan Meeting, February 20–21, 1942—541
New England Section: Worcester, Massachusetts, March 28, 1942—724
New York State Section: Aurora, New York, Meeting, April 4, 1942—725
Southeastern Section: Oxford, Mississippi, Meeting, April 10–11, 1942—725
Ohio Section: Granville, Ohio, Meeting, April 18, 1942—729
Baltimore Meeting, May 1–2, 1942—730

Radiation
Finite self-energies, A. Landé, L. H. Thomas—543(A)
Positron annihilation radiation, R. Beringer, C. G. Montgomery—222
Radioactivity
β-ray spectra of Sc, G. P. Smith—578
β-rays from Br^{82}, M. Deutsch—672(L)
Conversion of γ-radiation, R. J. Bessey—544(A)
γ-radiation from Na^{21}, L. G. Elliott, M. Deutsch, A. Roberts—99(A)
Of some earths, C. S. Wu, E. Segrè—203(A)
Forbidden transitions, β-decay and electron capture and spins, R. E. Marshak—388(A), 431
γ-rays of Sb, G. S. Klaiber, G. Scharff-Goldhaber—733(A)
γ-rays from long period activities, M. Deutsch, A. Roberts, L. G. Elliott—389(A)
γ-rays from Hg, A. C. Helmholz—204(A)
From Au, W, and Dy, A. F. Clark—203(A), 242
Half-lives of β-transitions, C. L. Critchfield—387(A), 249; Greuling—568
Of I^{131}, J. R. Downing, M. Deutsch, A. Roberts—389(A), 686
Isomeric states in In, R. N. Smith—389(A)
La, isotopes of, K. E. Mounce, M. L. Pool, J. D. Kurbatov—389(A)
Of Nd-Il-Sm isotopes, J. D. Kurbatov, D. C. MacDonald, M. L. Pool, L. L. Quill—106(A)
Of Ni isotopes, M. E. Nelson, M. L. Pool, J. D. Kurbatov—105(A), 428
Of praseodymium isotopes, J. W. DeWire, M. L. Pool, J. D. Kurbatov—544(A), 564
Radiations of Co^{60}, M. E. Nelson, M. L. Pool, J. D. Kurbatov—733(A)
Se from As, C. V. Kent, J. M. Cork, W. G. Wadey—389(A)

Separation of nuclear isomers, E. P. Cooper—1
Theoretical half-lives of RaE and P^{32}, E. Greuling—732(A)

Raman spectra
Of acetylenes, resonance interaction, F. F. Cleveland, M. J. Murray—106(A)
Of *dl*- and meso-2,3-dibromobutane, H. J. Taufen, M. J. Murray, F. F. Cleveland—106(A)
Of gaseous and liquid states, J. R. Nielsen, N. E. Ward—383(A)
Of hexachloroethane, F. F. Cleveland, D. T. Hamilton, M. J. Murray—735(A)
Hindrance of resonance, R. H. Saunders, M. J. Murray, F. F. Cleveland—106(A)
Of thiophenol solutions, F. F. Cleveland, M. J. Murray, R. H. Saunders—386(A)

Relativity
Comparison spaces, W. Band—702
Five-dimensional field theories, P. G. Bergmann—731(A)
Matter waves and electricity, C. Lanczos—713
Is space-time flat? W. Band—698

Resistance, electrical (see **Electrical conductivity and resistance**)

Resonance radiation
Quenching and depolarization, S. Mrozowski—379(L)

Scattering of electrons, neutrons, and ions (see also **Electrons, scattering of; Electron diffraction**)
Analysis of single-scattering data, F. T. Rogers, Jr.—728(A)
Cross sections of C and H for neutrons, R. Sherr—734(A)
Deuterons in D_2 and H_2, energy loss, C. M. Crenshaw, V. J. Young, H. P. Manning—388(A)
Of deuterons by protons, D. J. Bohm, R. Thomas—203(A)
Electrical and anomalous scattering of mesotrons, R. P. Shutt—6
Electron polarization, C. G. Shull—198(L), 736(A)
Magnetic scattering of neutrons, M. Hamermesh—17
Multiple scattering of fast electrons, L. A. Kulchitsky, G. D. Latyshev—254
p-wave proton-proton scattering, E. C. Creutz, R. R. Wilson—388(A)
Of protons by deuterium, R. F. Taschek—13
Protons scattered by high energy neutrons, H. Tatel—450
Scattering of fast electrons, E. Bleuler, P. Scherrer, W. Zünti—95(L)
Scattering of fast neutrons, H. H. Barschall, R. Ladenburg—129

Solid state (see **Crystalline state**)

Spark discharge (see **Discharge of electricity, etc.**)

Specific heat
Of liquids, G. H. Wannier—391(A)

Spectra, absorption
Broadening in HCN, H. M. Foley—545(A)
Of $C^{13}O^{16}$, R. T. Lagemann—729(A)
In COOH and COHN dimers, G. A. Anslow—546(A)
Of chlorophyll preparations, V. M. Albers, H. V. Knorr—546(A)
Electronic levels of hydrogen and alkyl halides, R. S. Mulliken—277
Methyl iodide absorption bands, R. S. Mulliken, E. Teller—107(A), 283
Of monodeuterobenzene, C. A. Beck, H. Sponer—386(A)
Of *ms*-tetra porphine, D. Fry, V. M. Albers, H. V. Knorr—730(A)
Of phenol, ultraviolet, M. B. Hall—736(A)
Protein fabrics, G. A. Anslow—547(A)
Of Ag CN, infra-red, W. D. Stallcup, D. Williams—726(A)
Of sugars, ultraviolet, W. C. Bosch, E. W. Anderson—726(A)
Of sym-trichlorobenzene vapor, H. Sponer, M. B. Hall—107(A)
Test for Hg vapor, K. C. Clark, O. Oldenberg—100(A)
Of unsaturated aliphatic chains, theory of, U. Fano—736(A)
Of water molecule in crystals, W. Lyon, E. L. Kinsey—482

Spectra, atomic
Of Bi I, hyperfine structure, S. Mrozowski, F. Bueso-Sanllehí—108(A)
Of Cs II in ultraviolet, M. A. Wheatley, R. A. Sawyer—591
Configuration in Co, G. Racah—537(L)
Degeneracies, equivalent electrons, O. Laporte, J. R. Platt—305
Fine structure and series extension, alkali metals, H. R. Kratz—735(A)
Of Hg II and Hg III, structure of, S. Mrozowski—605
Of Nd II, W. E. Albertson, G. R. Harrison, J. R. McNally, Jr.—167
New type vector coupling, G. Racah—537(L)
Rydberg corrections for *D*-terms in He I, L. Pincherle—156
Term formulae for configuration d^5, O. Laporte—302
Theory of complex spectra, G. Racah—186
Triplets of He, D. R. Inglis—297

Spectra, general
Chemiluminescence of chlorophyll *a*, A. Stewart, H. V. Knorr, V. M. Albers—729(A)
Ozone and ultraviolet light, A. W. Ewell—724(A)
Pressure effects, H. M. Foley, D. M. Dennison—386(A)
Resonance broadening of Cs, C. Gregory—465

Spectra, molecular (see also **Molecular structure and constants**)
Analysis of 3200A band system of CS_2, G. T. Pelsor—384(A)
Bands from alkali metals, J. E. Mack, H. R. Kratz—735(A)
Bands in C_2H_6, C_2D_6 and C_2H_5D, L. R. Posey, E. F. Barker—546(A)
Energies of planar ZXY_2 molecules, S. Silver—383(A)
Erratum: Vibration-rotation energies of polyatomic molecules, H. H. Nielsen—540
Fluorescence and absorption of hydrogenated chlorophyll *a*, H. V. Knorr, V. M. Albers—546(A)
Infra-red bands of C_2H_4, L. G. Smith, W. M. Woodward—386(A)

Spectra, molecular (continued)
Intensity anomalies by collisions in perturbed rotational bands, H. Beutler, M. Fred—107(A)
Perturbations in cyanogen band, A. T. Wager—107(A)
Rotational structure of chlorine bands, J. B. Coon—107(A)
Spectroscopy, technique
Determination of traces of K, S. S. Ballard, C. B. Mills—108(A)
High pressure Hg lamps, C. Kenty—545(A)
Recording infra-red spectrometer, R. A. Oetjen, Chao-Lan Kao, H. M. Randall—547(A)
Statistical mechanics (see **Mechanics, statistical**)
Superconductivity (see **Electrical conductivity and resistance**)

Thermal conductivity
Paradox in theory, G. Jaffé—643
Of rectangular bar and cooling effect of fins, M. Avrami, J. B. Little—392(A)
Thermal transpiration, Bose-Einstein and Fermi-Dirac gas, D. V. Gogate, D. S. Kothari—349
Thermal diffusion
Elementary explanation, W. H. Furry—388(A)
In liquids, H. E. Carr—726(A)
Isotope separation factor, R. Simon—388(A)
Variation with temperature in A, L. G. Stier—740(A)
Thermal expansion
Of pure metals, F. C. Nix, D. MacNair—74
Of Zn crystals, W. P. Staker—653
Thermionic emission; Emitting surfaces
Absorption of Th on W single crystals, M. H. Nichols—390(A)
Anode effect in a triode, P. L. Copeland, G. G. Carne—103(A), 635
Properties of the Fe group, H. B. Wahlin—103(A)
Of Ta; temperature scale, M. D. Fiske—513
Thermionic properties of Fe group, H. B. Wahlin—103(A), 509
Transition, thermionic to cold emission, C. J. Mullin, E. Guth—542(A), 339

Vacuum tubes
Charge trapped on grid, P. L. Copeland, G. G. Carne—103(A), 635
Theory of magnetron, L. Brillouin—103(A)
Van der Waals' forces
Effect of double layer, W. G. Pollard—740(A)
Vaporization (see **Evaporation**)
Viscosity
Stokes' relation, L. Tisza—531

X-rays, absorption
K absorption of metal ions in solution, W. W. Beeman, J. A. Bearden—455
Structure of absorption edges, R. Smoluchowski—736(A)
Of 0.7 to 2.5 Mv, L. C. Van Atta, F. E. Myers, A. A. Petrauskas—99(A)
Structure region of the potassium *K* edge, J. B. Platt, L. G. Parratt—103(A)
X-rays, diffraction, scattering, reflection, refraction, and polarization
Diffuse reflection, H. A. Jahn, K. Lonsdale—375
Non-Laue reflections, D. S. Teague—204(A)
Polarized x-rays scattered by ferromagnetic substances, E. Rodgers—35
Temperature diffuse scattering, W. H. Zachariasen—103(A); J. Hamilton-Hall—158; M. Born—377
Thermal scattering in crystals, J. Weigle, C. S. Smith—23
X-rays, emission
Auger effect, relative intensities and widths, J. N. Cooper—234
Intensity and polarization, R. Weinstock—204(A)
L-series satellites lines, L. Pincherle—225
Production in range 0.7 to 2.5 Mv, L. C. Van Atta, F. E. Myers, A. A. Petrauskas—99(A)
Theory of continuous spectrum, R. Weinstock—584
X-rays, polarization
Intensity and polarization, R. Weinstock—204(A)
X-rays, tubes, apparatus
Detecting x-rays, comparison of methods, A. Eisenstein, N. S. Gingrich—104(A)

Zeeman effect
In Nd II, W. E. Albertson, G. R. Harrison, J. R. McNally, Jr.—167

Information For Contributors

THE Editors of THE PHYSICAL REVIEW would be aided in their task if the following items were used as a guide by all contributors.

MANUSCRIPTS

Send manuscripts to J. W. Buchta, Department of Physics, University of Minnesota, Minneapolis, Minnesota.

Papers must be in English, typewritten double spaced with wide margins on a durable white paper, preferably lettersize. The original copy, not the carbon, should be submitted.

For general style, spellings, abbreviations and form, recent issues of this journal should be consulted.

ABSTRACTS

An abstract must accompany each article. It should be adequate as an *index* and as a *summary*. As an index it should give all subjects, major and minor, concerning which new information is presented. As a summary it should give the conclusions of the article and all numerical results of general interest.

MATHEMATICAL EXPRESSIONS

Make all expressions clear to the typesetter. Identify in the margin of the manuscript Greek letters and unusual symbols.

Use fractional exponents instead of root signs.

Avoid complicated exponents and subscripts. Should it be necessary to repeat a complicated expression a number of times it should be represented by some convenient symbol.

The solidus (/) should be used wherever possible for fractions.

REFERENCES

References should appear as footnotes, numbered consecutively, and arranged thus:

[1] A. B. Smith, Phys. Rev. **41**, 852 (1932).
[2] G. R. Harrison, *Atoms in Action* (William Morrow & Company, New York, 1939), first edition, p. 30.

FIGURES AND TABLES

Legends for figures must accompany manuscript. Each table should have a caption. These in all cases should be complete in themselves so as to make the data intelligible to the reader without reference to the text. Each figure and table should be cited in sequence in the text.

LINE DRAWINGS AND PHOTOGRAPHS

Plan figures for reduction to one third or one fourth the original size. Wherever possible arrange figures so that after reduction they will not be wider than three inches. Lettering must be large enough to be readable (about 3 mm high) after reduction. The figures should be so arranged that the space is used efficiently.

Line drawings must be made with India ink on white paper or tracing cloth. Coordinate paper is not desirable, but if used must be blue-lined and all coordinates to be reproduced drawn with India ink.

Drawings which cannot be used will be returned to the author.

Photographs of drawings seldom are satisfactory. They often do not show clear black and white contrasts and are not suitable for relettering which is sometimes necessary. Photographs of apparatus seldom give as much information as drawings.

Please avoid round or oval photographs.

ALTERATIONS

Take great care that each manuscript is typographically accurate. A limited number of alterations in proof are unavoidable, but the cost of making extensive alterations after the article has been set in type will be charged to the author.

Proof and all correspondence concerning papers in the process of publication should be addressed to the Publications Manager, American Institute of Physics, 175 Fifth Avenue, New York, New York.

ysics Lib
JUN 25 1942

THE PHYSICAL REVIEW

VOLUME 61 *Second Series* NUMBERS 11 AND 12

JUNE 1 AND 15, 1942

Published for the

AMERICAN PHYSICAL SOCIETY

by the

AMERICAN INSTITUTE OF PHYSICS
Incorporated

LANCASTER, PA., AND NEW YORK, N. Y.

THE PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

Published by the American Institute of Physics for the

AMERICAN PHYSICAL SOCIETY

Officers

President

P. W. BRIDGMAN
Harvard University
Cambridge, Massachusetts

Vice President

A. W. HULL
General Electric Company
Schenectady, New York

Secretary

K. K. DARROW
Bell Telephone Laboratories
Office:
Columbia University
New York, New York

Treasurer

G. B. PEGRAM
Columbia University
New York, New York

Local Secretary for the Pacific Coast

R. T. BIRGE
University of California
Berkeley, California

Editor

JOHN T. TATE*
University of Minnesota
Minneapolis, Minnesota

* On leave for 1942.

BOARD OF EDITORS

JOHN T. TATE, *Editor (on leave)* J. W. BUCHTA, *Acting Editor*

Associate Editors

S. K. ALLISON	A. C. G. MITCHELL	W. H. FURRY
P. M. MORSE	I. I. RABI	LUIS ALVAREZ
J. A. WHEELER	G. E. UHLENBECK	E. M. MCMILLAN

Manuscripts for publication should be submitted to J. W. Buchta, University of Minnesota, Minneapolis, Minnesota.

Proof and all correspondence concerning papers in the process of publication should be addressed to the Publications Manager, American Institute of Physics, 175 Fifth Avenue, New York, New York.

Subscription Price

United States and Canada $15.00
Elsewhere $16.50

Back Numbers

Complete set: Series 2,[1] Vol. 1, 1913–Vol. 60, 1941—$435.00
Yearly rate: $16.50
Single copies: $1.50 each prior to July, 1929;
$0.75 each July, 1929–December, 1941.
Current issues: $1.50 each.

Subscriptions and orders for back numbers should be addressed to Prince and Lemon Streets, Lancaster, Pennsylvania, or to the American Institute of Physics, 175 Fifth Avenue, New York, New York.

Changes of address in the case of members of the American Physical Society should be addressed to the Treasurer; in the case of other subscribers to the Publications Manager.

[1] For Series 1 inquire of Physics Department, Cornell University, Ithaca, New York.

The Physical Review is published monthly at Prince and Lemon Streets, Lancaster, Pennsylvania.

Entered at the Post Office at Lancaster, Pennsylvania, as second class matter.

Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized September 6, 1926.

THE AMERICAN INSTITUTE OF PHYSICS

INCORPORATED

ADMINISTRATIVE STAFF

HENRY A. BARTON, *Director*

MADELINE M. MITCHELL, *Publications Manager*

JOHN T. TATE, *Adviser on Publications*

Office: 175 Fifth Avenue, New York, New York

JOURNALS

THE PHYSICAL REVIEW
REVIEWS OF MODERN PHYSICS
JOHN T. TATE, *Editor (on leave)*
J. W. BUCHTA, *Acting Editor*

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA
GEORGE R. HARRISON, *Editor*

THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA
FLOYD A. FIRESTONE, *Editor*

AMERICAN JOURNAL OF PHYSICS
(Formerly THE AMERICAN PHYSICS TEACHER)
DUANE ROLLER, *Editor*

THE REVIEW OF SCIENTIFIC INSTRUMENTS
GAYLORD P. HARNWELL, *Editor*

THE JOURNAL OF CHEMICAL PHYSICS
JOSEPH E. MAYER, *Editor*

JOURNAL OF APPLIED PHYSICS
ELMER HUTCHISSON, *Editor*

GOVERNING BOARD

PAUL E. KLOPSTEG, *Chairman*
Central Scientific Company

GEORGE B. PEGRAM, *Secretary*
Columbia University

For the American Physical Society:

L. A. DUBRIDGE
University of Rochester

GEORGE B. PEGRAM
Columbia University

JOHN T. TATE
University of Minnesota

For the Optical Society:

R. C. GIBBS
Cornell University

A. C. HARDY
Massachusetts Institute of Technology

K. S. GIBSON
National Bureau of Standards

For the Acoustical Society of America:

FLOYD A. FIRESTONE
University of Michigan

HARVEY FLETCHER
Bell Telephone Laboratories

WALLACE WATERFALL
The Celotex Corporation

For the Society of Rheology:

R. B. DOW
Aberdeen Proving Ground

HERMANN MARK
Brooklyn Polytechnic Institute

N. W. TAYLOR
The Pennsylvania State College

For the American Association of Physics Teachers:

GEORGE R. HARRISON
Massachusetts Institute of Technology

PAUL E. KLOPSTEG
Central Scientific Company

A. G. WORTHING
University of Pittsburgh

The American Institute of Physics is a membership corporation of which five societies are the founding members. These five societies are the principal national societies devoted to pure and applied physics in America. Their names, and those of their representatives who form the Governing Board of the Institute, are given above. The principal work of the Institute is the publication of journals sponsored by the societies or by itself. The names and the editors of the journals are also listed above.

The broad purpose of the Institute is to represent, in all matters of wide or common interest, the five thousand or more members and subscribers associated with the Founder Societies and the journals. It aims to advance the science and profession of physics, and to promote cooperation between pure research, the applied sciences and the industries. To achieve these aims, it is greatly in need of an endowment and is empowered by law to administer grants and funds of any kind.

CONTENTS

PHYS. REV. 61 (1942) JUNE 1 AND 15

Further Measurements of the Mesotron Lifetime . . . . . BRUNO ROSSI, KENNETH GREISEN, JOYCE C. STEARNS, DAROL K. FROMAN, AND PHILLIPP G. KOONTZ 675

Electric and Magnetic Effects of Cosmic Rays . . . . . FOSTER EVANS 680

Nature of the Soft Component of Cosmic Rays at 3500 Meters Altitude . . PIERRE V. AUGER 684

Disintegration Schemes of Radioactive Substances. III. I^{131} . . . . . J. R. DOWNING, M. DEUTSCH, AND A. ROBERTS 686

Experimental Evidence for the Existence of a Neutrino . . . . . JAMES S. ALLEN 692

Is Space-Time Flat? . . . . . WILLIAM BAND 698

Comparison Spaces in General Relativity . . . . . WILLIAM BAND 702

Total Secondary Electron Emission from Thin Films of Sodium on Tungsten . . . . . KENNETH G. MCKAY 708

Matter Waves and Electricity . . . . . CORNELIUS LANCZOS 713

Letters to the Editor:

Theory of Absolute Reaction Rates and the Conductivity of Hydrocarbons at High Field Strengths . . . . . NORMAN DAVIDSON 721

Ultimate Resolving Power of the Electron Microscope . . . . . L. I. SCHIFF 721

Observation of Crystalline Reflections in Electron Microscope Images . . . . . JAMES HILLIER AND RICHARD F. BAKER 722

Proceedings of the American Physical Society:

New England Section Meeting, March 28, 1942: Minutes and Abstracts 1–8 724

New York State Section Meeting, April 4, 1942 725

Southeastern Section Meeting, April 10–11, 1942: Minutes and Abstracts 1–17 725

Ohio Section Meeting, April 18, 1942: Minutes and Abstracts 1–4 729

Baltimore Meeting, May 1–2, 1942: Minutes and Abstracts 1–43 730

Author Index to Volume 61 742

Analytic Subject Index to Volume 61 750

Volume Table of Contents iii

LANCASTER PRESS, INC., LANCASTER, PA.